

# ESC<sup>\*</sup> Supernova spectroscopy of non-ESC targets

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## ABSTRACT

**Aims.** We present the spectra of 36 Supernovae (SNe) of various types, obtained by the European Supernova Collaboration. Because of the spectral classification and the phase determination at their discovery the SNe did not warrant further study, and the spectra we present are the only available for the respective objects. In this paper we present and discuss this material using a new software for the automated classification of SNe spectra.

**Methods.** As a validation of the software, we verify the classification and phase estimate reported for these objects in their discovery / classification circulars. For the comparison, the software uses the library of template spectra of Padova-Asiago Supernova Archive (ASA).

**Results.** For each spectrum of our sample we present a brief, individual discussion, highlighting the main characteristics and possible peculiarities. The comparison with ASA spectra confirms the previous classification of all objects and refines the age estimates. For our software we determine numerical limits of “safe” spectral classification and the uncertainties of the phase determination.

**Key words.** supernovae: general – methods: data analysis

## 1. Introduction

Supernovae (SNe) are the catastrophic events terminating the evolution of different kinds of stars. Two main explosion mechanisms are commonly considered: the core collapse of a massive star and the thermonuclear runaway of a white dwarf accreting material from a companion. Core-Collapse (CC) SNe include several types (SNe II, Ib, Ic, IIn, etc) while the Thermonuclear SNe are observationally called SNe Ia (see Turatto 2003; Turatto et al. 2007, for reviews).

CC SNe are important tools in understanding the latest epochs of the life of massive stars, the chemical enrichment of galaxies and the star formation history of the universe (e.g. Botticella et al. 2007), while type-Ia Supernovae (SNe Ia), on the account of their high luminosity and homogeneous properties, are considered one of the most accurate distance indicators. Indeed, the measurement of SNe Ia at high redshifts gives the best evidence that we are living in an accelerating Universe (see Perlmutter & Schmidt 2003, and references therein). However, the fact that progenitor systems of SNe Ia and their explosion mechanisms are still debated leaves room for a possible luminosity evolution with redshift, which would undermine the results reported so far. Studies of larger and larger datasets con-

firmed the existence of rather vast variety of SN Ia properties (e.g. Benetti et al. 2004, 2005).

The European Supernova Collaboration (ESC) was a European Research Training Network (RTN), founded in 2002 with the goal to improve our understanding of SN Ia physics through a detailed study of nearby ( $v_{\text{rec}} < 6000 \text{ km s}^{-1}$ ) SNe Ia. During the following years detailed spectroscopic and photometric monitoring of 15 nearby SNe Ia (plus 1 SN Ic) was carried out. The results for 10 of these objects are already published in dedicated papers (Benetti et al. 2004; Elias-Rosa et al. 2006, 2008; Pignata et al. 2004b; Kotak et al. 2005; Stanishev et al. 2007; Taubenberger et al. 2006, 2008; Altavilla et al. 2007; Pastorello et al. 2007a,c; Garavini et al. 2007). A number of papers with results on the other objects are in preparation (Pignata et al., Stanishev et al., Kotak et al., Salvo et al., Kerzendorf et al., Elias-Rosa et al., in preparation). Using also SNe Ia from this sample, analyses of systematic properties of SNe Ia have been presented in Benetti et al. (2005), Mazzali et al. (2005), Hachinger et al. (2006) and Mazzali et al. (2007).

In order to select RTN target candidates, prompt classification of newly discovered SNe was required. Thereafter some objects became targets of extensive monitoring, many others did not pass the RTN selection criteria and no follow-up observations were triggered. For these SNe only classification spectra are therefore available. In this paper we present spectra of 36 SNe, obtained during the ESC-related programs, for which

\* European Supernova Collaboration  
<http://www.mpa-garching.mpg.de/~rtn>

**Table 1.** SN sample and observations

| SN     | Discovery | Acquisition | Instrumentation      | Spectral range            | Resolution <sup>1</sup> | Reference              |
|--------|-----------|-------------|----------------------|---------------------------|-------------------------|------------------------|
|        | DD/MM/YY  | DD/MM/YY    | Telescope+Instrument | Å                         | Å                       | IAUC / CBET            |
| 2002an | 22/01/02  | 05/02/02    | 1.82m Mt.Ekar+AFOSC  | 3700 - 7620               | 25                      | 7805, 7808, 7818, 7828 |
| 2002bh | 24/02/02  | 05/03/02    | 1.82m Mt.Ekar+AFOSC  | 4000 - 7600               | 26                      | 7837, 7840, 7844       |
| 2002cs | 05/05/02  | 07/05/02    | TNG+DOLORES          | 3500 - 7930               | 15                      | 7891, 7894             |
| 2002dg | 31/05/02  | 15/06/02    | ESO NTT+EMMI         | 3800 - 9330               | 10                      | 7915, 7922             |
| 2002dm | 04/05/02  | 15/06/02    | ESO VLT U4+FORSS2    | 4290 - 10250 <sup>2</sup> | 12                      | 7921, 7923             |
| 2002ej | 09/08/02  | 30/08/02    | 1.82m Mt.Ekar+AFOSC  | 3800 - 7630               | 25                      | 7951, 7963             |
| 2002hg | 28/10/02  | 02/11/02    | CA 2.2m+CAFOS        | 3600 - 8690               | 12                      | 8004, 8007             |
| 2002hm | 05/11/02  | 06/11/02    | CA 2.2m+CAFOS        | 3500 - 8700               | 13                      | 8009                   |
| 2002hy | 12/11/02  | 15/11/02    | ESO 3.6m+EFOSC2      | 3500 - 9820               | 13                      | 8016, 8019             |
| 2003hg | 18/08/03  | 22/08/03    | 1.82m Mt.Ekar+AFOSC  | 3800 - 7360               | 24                      | 8184, 8187, 40         |
| 2003hn | 25/08/03  | 26/08/03    | ESO 3.6m+EFOSC2      | 3600 - 9960               | 13                      | 8186, 8187             |
| 2003ie | 19/09/03  | 22/09/03    | 1.82m Mt.Ekar+AFOSC  | 4000 - 7440               | 25                      | 8205, 8207             |
| 2004G  | 19/01/04  | 21/01/04    | CA 2.2m+CAFOS        | 3500 - 8090               | 14                      | 8272, 8273             |
| 2004aq | 02/03/04  | 10/03/04    | NOT+ALFOSC           | 3900 - 8910               | 19                      | 8301                   |
| 2004bs | 16/05/04  | 19/05/04    | CA 2.2m+CAFOS        | 3800 - 8650               | 12                      | 8341, 66, 8344, 8348   |
| 2004cc | 10/06/04  | 14/06/04    | NOT+ALFOSC           | 3500 - 8990               | 19                      | 8350, 8353             |
| 2004dg | 19/07/04  | 21/07/04    | 1.82m Mt.Ekar+AFOSC  | 3800 - 7780               | 25                      | 8375, 8376, 8383       |
| 2004dk | 30/07/04  | 03/08/04    | CA 2.2m+CAFOS        | 3500 - 8750               | 12                      | 8377, 8379, 8404, 75   |
| 2004dn | 29/07/04  | 05/08/04    | CA 2.2m+CAFOS        | 3800 - 8690               | 12                      | 8381                   |
| 2004fe | 30/10/04  | 02/11/04    | NOT+ALFOSC           | 3500 - 8900               | 19                      | 8425, 8426             |
| 2004go | 18/11/04  | 07/12/04    | 1.82m Mt.Ekar+AFOSC  | 3800 - 7580               | 24                      | 8448, 8450, 8454       |
| 2005G  | 14/01/05  | 18/01/05    | 1.82m Mt.Ekar+AFOSC  | 3600 - 7300               | 24                      | 8465, 8568             |
| 2005H  | 15/01/05  | 17/01/05    | CA 2.2m+CAFOS        | 4000 - 8700               | 10                      | 8467                   |
| 2005I  | 15/01/05  | 18/01/05    | CA 2.2m+CAFOS        | 3800 - 8610               | 12                      | 8467                   |
| 2005N  | 19/01/05  | 22/01/05    | CA 2.2m+CAFOS        | 3700 - 8600               | 12                      | 8470                   |
| 2005V  | 30/01/05  | 31/01/05    | CA 2.2m+CAFOS        | 3500 - 8780               | 14                      | 8474, 8572             |
| 2005ab | 05/02/05  | 09/02/05    | 1.82m Mt.Ekar+AFOSC  | 4250 - 8070               | 25                      | 8478, 8479, 8480       |
| 2005ai | 12/02/05  | 14/02/05    | CA 2.2m+CAFOS        | 3800 - 8700               | 12                      | 8486, 8487             |
| 2005br | 28/03/05  | 25/05/05    | ESO VLT U1+FORSS2    | 4000 - 9710 <sup>2</sup>  | 12                      | 8516, 156, 8538        |
| 2005bs | 19/04/05  | 25/05/05    | ESO VLT U1+FORSS2    | 3800 - 9290 <sup>2</sup>  | 12                      | 8517, 143, 156, 8538   |
| 2005cb | 13/05/05  | 25/05/05    | ESO VLT U1+FORSS2    | 3700 - 9720 <sup>2</sup>  | 12                      | 8530, 156, 8538        |
| 2005ce | 28/05/05  | 29/05/05    | NOT+ALFOSC           | 3400 - 8800               | 19                      | 158, 159               |
| 2005de | 02/08/05  | 06/08/05    | CA 2.2m+CAFOS        | 3500 - 8640               | 15                      | 8580, 191, 8581, 193   |
| 2005dv | 04/09/05  | 09/09/05    | CA 2.2m+CAFOS        | 3500 - 8710               | 12                      | 8598, 217, 218         |
| 2005dz | 10/09/05  | 12/09/05    | NOT+ALFOSC           | 3400 - 8850               | 19                      | 222, 225               |
| 2005kl | 22/11/05  | 24/11/05    | CA 2.2m+CAFOS        | 4200 - 8750               | 12                      | 8634, 300, 305         |

Notes:

<sup>1</sup> measured on the FWHM of the night sky lines when available, otherwise the typical FWHM for the respective telescope-instrument combination is written<sup>2</sup> obtained by merging two spectra with different spectral coverage

1.82m Mt.Ekar + AFOSC - 1.82m Copernico Telescope + Asiago Faint Object Spectrograph and Camera, Asiago, Italy

TNG + DOLORES - 3.5m Telescopio Nazionale Galileo + Device Optimized for the LOw RESolution, La Palma, Spain

ESO NTT + EMMI - 3.5m New Technology Telescope + ESO Multi-Mode Instrument, ESO La Silla, Chile

ESO VLT U1, U4 + FORSS2 - 8m Very Large Telescope, Unit 1, 4 + visual and near UV FOcal Reducer and low dispersion Spectrograph 2, ESO Paranal, Chile

CA 2.2m + CAFOS - 2.2m Calar Alto Telescope + Calar Alto Faint Object Spectrograph, Almería, Spain

ESO 3.6m + EFOSC2 - 3.6m Telescope + ESO Faint Object Spectrograph and Camera (v.2), ESO La Silla, Chile

NOT + ALFOSC - Nordic Optical Telescope + AndALucia Faint Object Spectrograph and Camera, La Palma, Spain

follow-up observations were not activated. These data have not been studied or published so far although in some cases, they contain interesting information. In particular, some of these spectra (4) were obtained at or before maximum light when unique information about the physical conditions and chemical structure of the progenitor star can be retrieved.

The spectra have been classified by means of a new automated tool, specifically developed for this purpose, which compares an input spectrum with the spectra of the Padova-Asiago Supernova Archive (ASA), and identifies the best matching tem-

plate spectrum. In this way it is possible to determine the spectral classification and the age of the new objects. A set of type-Ia SN spectra of ESC objects with good temporal coverage was also used to test and calibrate the software tool.

The structure of the paper is the following: in Sect. 2 we present our SN sample, observations and data reduction techniques. In Sect. 3 the issue of SN spectral classification is addressed, and in Sect. 4 the software is presented. A discussion of individual spectra is done in Sect. 5 and finally the Sect. 6 gives a short summary.

## 2. SN sample, observations and data reduction

The sample of 36 SNe is presented in Table 1, where also the information on instrumental configurations and observational details is listed. Seven different telescope+instrument combinations have been used for the observations. The last column of the table contains the references for the discovery and the classification circulars (IAUC, CBET) for each object.

All two-dimensional images were pre-reduced (trimmed, overscan, bias and flatfield corrected) with standard IRAF<sup>1</sup> subroutines. Further data processing was performed using the procedures from the IRAF CTIOSLIT package. In particular, after the optimised extractions performed with the APALL task, the one-dimensional spectra were wavelength-calibrated by comparison with spectra of arc lamps obtained during the same night and with the same instrumental configuration. The wavelength calibration was checked against bright night-sky emission lines. The SN spectra were then flux-calibrated using response curves derived from the spectra of standard stars preferably observed during the same night<sup>2</sup>.

In some cases two spectra of the same object observed during the same night in different spectral ranges were merged into a single spectrum to gain a wider wavelength coverage and/or higher signal-to-noise ratio (SNR).

## 3. SN classification

Prompt SN type determination is important in the study of SNe. In particular, the success of extensive and time consuming observational campaigns depends crucially on the proper planning of observations, typically obtained in Target of Opportunity mode. A rapid SN classification is usually performed on the basis of one optical spectrum (usually obtained near maximum light) and in general is quite reliable. In a few cases a definitive classification requires the analysis of the spectral evolution.

In the earliest phase when the SN is optically thick, the photosphere emits a continuum radiation field, while line formation occurs above. The ejecta is expanding and the lines are characterised by P-Cygni (P-Cyg) profiles, an emission peak near the rest wavelength of the line and a blueshifted absorption feature. The emission peak is formed by line scattering into the line of sight of photons emitted by the photosphere and would be symmetrical to the line center wavelength if there was not the absorption. The absorption is formed by scattering out the line of sight of photospheric photons emitted toward the observer. Since this occurs in front of the photosphere, the absorption is blueshifted (see Jeffery & Branch 1990, for a review on spectra formation).

Type-Ia SNe are classified by the presence of lines of intermediate mass elements such as Si, Ca and S during the maximum light phase and by the absence of H at any time. Type-Ib SNe are spectroscopically classified by the absence of H Balmer and Si II lines and by the presence of He I features, though, as Branch et al. (2002) showed, weak, broad H $\alpha$  may also be present. Type-Ic SNe are similar, but with the absence of He lines, though some weak contamination of He seems to be common to several type-Ic SNe (Filippenko et al. 1995). Type-II SNe are characterised by strong H Balmer lines.

Most of the SNe fall in one of the above mentioned 4 classes. However, there is an increasing number of peculiar objects, with unprecedented properties and evolution (e.g. SN 2006jc, for

which type-Ibn label was coined, Pastorello et al. 2007b, 2008), that do not fit within the scheme above. The current taxonomy of SNe is therefore incomplete, ambiguous and not fully satisfactory (see Turatto et al. 2007, and references therein). In a situation in which the classification criteria are not exhaustive, a conservative approach for SN classification is via comparison with other SNe. With this motivation, our group has developed a tool that compares a given input spectrum with the set of spectra from ASA, a large archive of SN spectra, collected by the members of the group during the last decades.

## 4. SN spectra comparison tool

A few groups (see Blondin & Tonry 2007, for a discussion) have developed software tools for SN spectra analysis. Using different technical approaches from  $\chi^2$  minimisation to cross-correlation, these tools aim at different immediate results, from rapid automatic SN spectra classification to quantification of spectral differences. The goal of our software is the quantitative classification of SN spectra by comparison with a large set of template spectra of various SN types at different phase.

The Padova Supernova Spectra compARison TOOL (passpartoo) is a collection of software procedures performing automatic comparison of SN spectra. Designed for different purposes and working with slightly different algorithms, all the procedures carry out an automatic comparison of a given (input) spectrum with a set of well-studied SN spectra (templates), in order to find the template spectrum that is most similar to the given one. The first version of the tool was presented in Harutyunyan et al. (2005). In this paper we used the GEneric cLAssification TOol (GELATO), which is a software for objective classification of SN spectra.

One of the major issues to solve is the treatment of reddening, due both to the Galaxy and to the SN host. We wanted our tool to minimise the impact of the reddening on the comparison result with no assumption on the reddening law, which can be very unusual (cfr. Elias-Rosa et al. 2006, 2008). To this aim, GELATO divides the input and every template spectrum in a number of separate spectral bins. This approach for spectra comparison was discussed in Riess et al. (1997) and Rizzi (1998) and has the advantage of giving priority to the presence and strength of spectral features. The bins are selected to contain the spectral features most significant for SN classification and dating. The same set of bins is adopted for comparison of spectra of all types with satisfactory results. The current version of GELATO uses 11 bins, 8 of which are from Riess et al. (1997), slightly modified to meet few technical requirements, while 3 have been added to include other spectral features and to enlarge the working spectral range. Table 2 lists the GELATO bins and the corresponding main spectral features.

The GELATO code works as follows: for all the  $N$  bins of an input spectrum it computes  $\delta_j$ , the mean relative distance between the  $j$ -th bin of the input spectrum and the corresponding bin of the template, scaled in flux to match the input one. This operation is iterated through all the template spectra and the average of  $\delta_j$  values for each template spectrum is calculated. If  $f_i$  is the input spectrum at wavelength  $\lambda_i$  and  $F_i$  the template spectrum, we define  $\delta_j$  as follows:

$$\delta_j = \frac{1}{n \cdot \langle f \rangle_j} \sum_{i=1}^n |f_i - F_i^{norm}|, \quad (1)$$

where  $n$  is the number of spectral elements in the bin,  $F_i^{norm}$  is the  $F_i$  flux scaled to the input spectrum flux within the given

<sup>1</sup> Image Reduction and Analysis Facility, <http://iraf.noao.edu>

<sup>2</sup> For a detailed discussion on data reduction techniques see, for instance, Pastorello et al. (2007a).

**Table 2.** GELATO bins with wavelength ranges and corresponding main spectral features.

| Bins | Range<br>Å  | SN spectra features |             |                              |
|------|-------------|---------------------|-------------|------------------------------|
|      |             | Ia                  | Ib/c        | II                           |
| 1    | 3504 - 3792 | Ca II               | Ca II       | Ca II                        |
| 2    | 3800 - 4192 | Si II, Ca II        | Ca II       | Ca II, H <sub>δ</sub>        |
| 3    | 4200 - 4576 | Mg II, Fe II        | Fe II       | Mg II, Fe II, H <sub>γ</sub> |
| 4    | 4584 - 4936 | Fe II               | Fe II       | Fe II, H <sub>β</sub>        |
| 5    | 4944 - 5192 | Fe II               | Fe II       | Fe II                        |
| 6    | 5200 - 5592 | S II                | S II, OI    | S II                         |
| 7    | 5600 - 5896 | Si II, Na I         | Na I, He I  | Si II, Na I                  |
| 8    | 5904 - 6296 | Si II               | He I        | Si II                        |
| 9    | 6304 - 6800 | Fe II               | Si II, He I | O I, H <sub>α</sub>          |
| 10   | 6808 - 7904 | O I                 | O I         | O I                          |
| 11   | 7912 - 9000 | Ca II               | Ca II       | Ca II                        |

bin, and  $\langle f \rangle_j$  is the mean value of the flux in the bin. Then, the average of  $\delta_j$  values is computed as:

$$\Delta = \frac{1}{N} \sum_{j=1}^N \delta_j, \quad (2)$$

where  $N$  is the number of bins. The most similar template to the input spectrum is the one that minimises the value of  $\Delta$ . Before the comparison a boxcar smoothing is performed on all spectra to reduce high-frequency noise components. After tests with artificial noise addition, a box size corresponding to  $\sim 40$ - $70$  Å is adopted to perform the smoothing. This smoothing is sufficient to remove high-frequency noise components and at the same time preserves the spectral features. Figure 1 shows the original and smoothed spectra of SN 2002ej (cfr. Section 5).

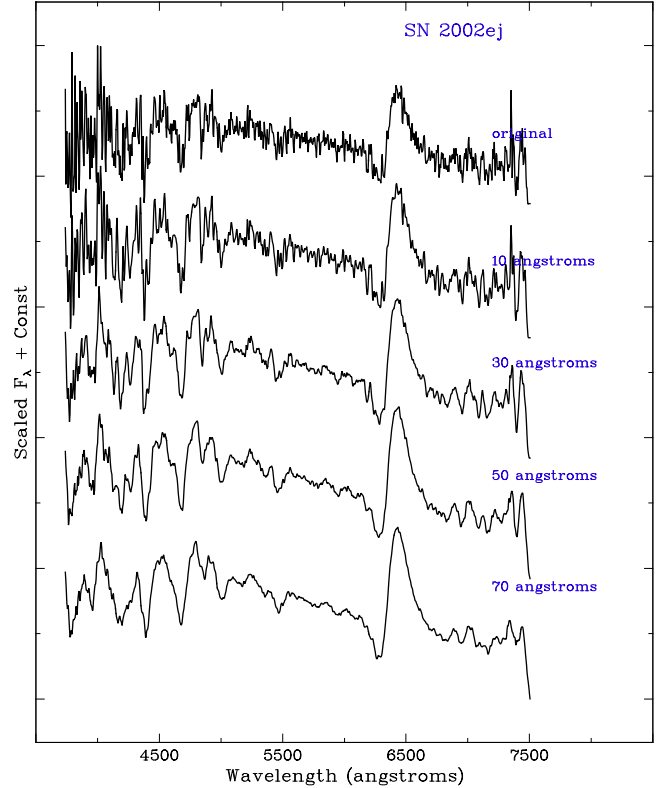
The software achieves the goal of finding the best fitting archive spectrum to a given input spectrum, through the minimisation of  $\Delta$  values. However,  $\Delta$  alone does not describe the quality of the fit, which is necessary for a quantitative comparison of the fits. Thus, we tried to define a quantitative value providing a measure of quality of fits. In general, we noted that the values of  $\Delta$  computed for the cases of spectra with dominating continuum and weak spectral features are systematically lower than those of spectra having many strong spectral features which can vary in relative intensities and position. To account for this, we weighted the  $\Delta$  values using coefficients that indicate whether the spectra are more or less feature-rich. We defined the feature-parameter (FP) as follows:

$$FP = \frac{1}{N} \sum_{j=1}^N \frac{1}{n} \sum_{i=1}^n \frac{|f_i - F_i^{flat}|}{\langle sp \rangle_j}, \quad (3)$$

where  $F_i^{flat}$  is the best fitting straight line to the spectrum in the given bin. Then, for each fit we define the quality of fit (QoF) value by the following expression:

$$QoF = \left( \frac{\Delta}{FP} \right)^{-1}. \quad (4)$$

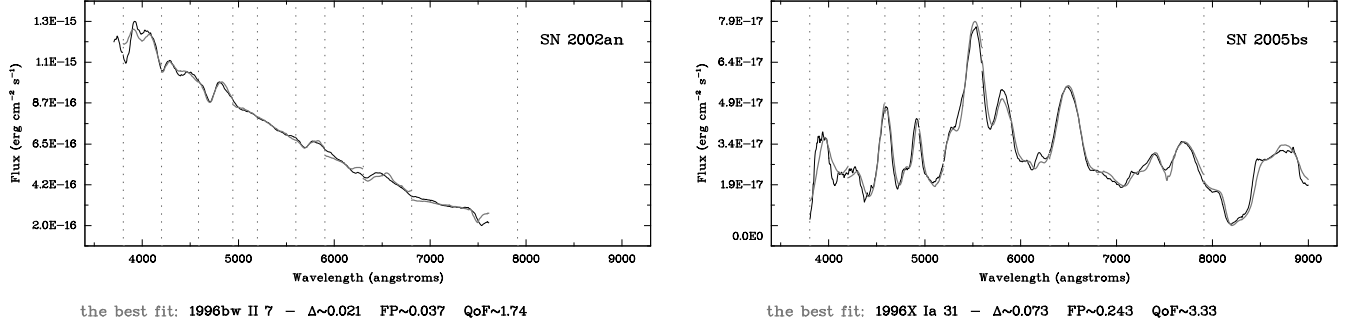
The QoF allows a numerical estimate of the quality of the fit, which can be used to compare the fits to different SN spectra. Table 4 reports the QoF values of the best fits to our set of spectra. In Figure 2 the graphical outputs of GELATO for the cases of SN 2002an and 2005bs are presented. In the figures the

**Fig. 1.** The original and smoothed spectra of SN 2002ej (Section 5). The spectra are in the parent galaxy restframe. The number near smoothed spectra are the corresponding box sizes.

smoothed versions of the input spectrum (black line) and best fitting template (gray line) together with bin boundaries (dotted lines) are displayed. The  $\Delta$  value of the fit in the SN 2002an case is smaller than that of the SN 2005bs case ( $\sim 0.02$  and  $0.07$ , respectively), but SN 2005bs has a greater FP (i.e. has more prominent features) than SN 2002an. The resulting QoF is greater for SN 2005bs ( $\sim 3.3$ ) than for SN 2002an ( $\sim 1.7$ ), thus according to GELATO the former should be regarded as a better fit than the latter. Further discussion for these spectra can be found in Section 5.

We tested the QoF values comparing spectra to different sets of templates. The results combined with visual inspections of the fits showed that  $QoF \geq 1.4$  means a high / satisfactory quality of the fit and safe SN type determination, while  $QoF < 1$  occurs when the input has no match in the archive. Intermediate values  $1 \leq QoF < 1.4$  may result both for fair/good fits with correct type detection or poor fits with incorrect type detection. Further tests will refine the QoF and establish the confidence levels.

We stress that thanks to the above mentioned subdivision in spectral bins, the best fit procedure depends very little on the slope of the continuum, hence reddening. This can be seen, for example, in the SN 2004aq spectrum fit by SN 1991al (Fig. 7d), for which the  $QoF = 2.95$ , despite the significant difference in SED. To verify this we used the original spectrum of SN 2005bs (see Section 5 and Fig. 8j) and progressively reddened it up with two reddening laws ( $R_V = 3.1$  and  $1.8$ , Elias-Rosa et al. 2006). Then we searched the best fitting templates with GELATO. Table 3 summarizes the results. The best fitting template for all the cases was found to be SN 1996X 31 day after maximum, though with slightly decreasing QoF. The test confirms



**Fig. 2.** The graphical output of GELATO for the cases of SN 2002an and SN 2005bs from our sample. The spectra are in the parent galaxy rest frame. The black lines are the input spectra and the gray ones the best fitting template spectra, divided in bins and scaled in flux to match the input spectra in the respective bins.

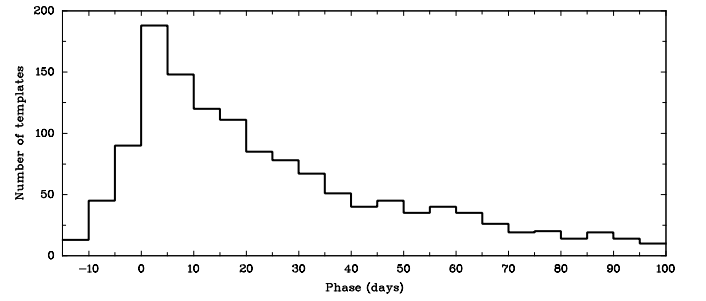
**Table 3.** Comparison results for reddened spectra of SN 2005bs.

| E(B-V) | $R_V=3.1$ |     | $R_V=1.8$ |     | Best template |
|--------|-----------|-----|-----------|-----|---------------|
|        | $A_V$     | QoF | $A_V$     | QoF |               |
| 0.0    | 0         | 3.3 | 0         | 3.3 | SN 1996X      |
| 0.16   | 0.5       | 3.1 | 0.3       | 3.1 | SN 1996X      |
| 0.32   | 1         | 2.8 | 0.6       | 2.9 | SN 1996X      |
| 0.48   | 1.5       | 2.6 | 0.9       | 2.7 | SN 1996X      |
| 0.64   | 2         | 2.3 | 1.2       | 2.4 | SN 1996X      |

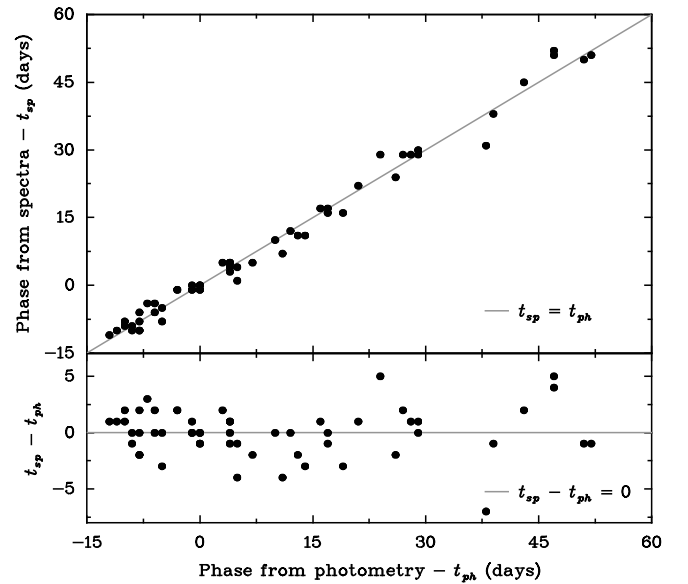
that GELATO is little sensible to the amount of reddening and to the reddening law.

The second crucial ingredient for the automated spectra classification, besides the software tool, is the availability of an extended archive of spectra. Spectra of all SN types from ASA are used as templates for the comparison procedure. These spectra have been collected by the Padova SN group in the course of several long-term projects devoted to the study of the physical properties of SNe including type-Ia SN spectra obtained by the ESC. The archive has also been enriched with publicly available material from the literature. Table 5 lists the archive content on December 2007. It provides the type, redshift, number spectra and phase range of the spectra for each SN. The information about the types and redshifts of SNe are obtained from the up-to-date version of the Asiago SN catalogue (Barbon et al. 1999). Currently there are spectra of 155 type-Ia (including objects like SN 1991T, 1991bg, 2000cx), 168 type-II (including SNe IIL, IIn, IIb) and 65 type-Ib/c SNe (including hypernovae and objects like 1997dq, 2006jc), for a total database of over 2500 spectra. Figure 3 shows the distribution of the templates on the basis of their phase. As one can see from the figure, the template temporal coverage is good at all phases though, as expected, the number of the template spectra is greater near maximum light.

In general, we adopt as an estimate of the input spectrum age the epoch of the corresponding best fitting template found by GELATO. We carried out several tests to check the ability of GELATO, in combination with ASA to determine the spectral age. To this aim, we used the spectra of a set of well-studied type-Ia SNe 2002bo, 2003cg, 2003du, 2004dt, 2004eo, 2005cf observed by the ESC, for which detailed light curves are available. Each spectrum of these objects was compared with those of a sample of a dozen of template SNe Ia, which include objects spanning the entire range of SN Ia properties (e.g. including SN

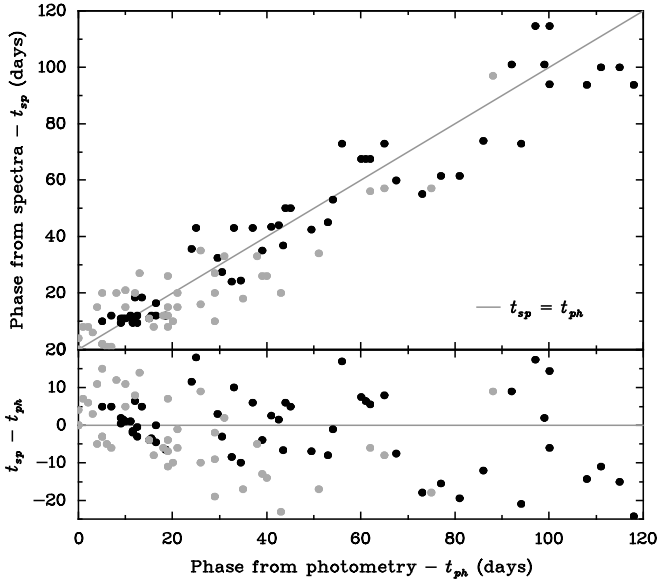


**Fig. 3.** The phase distribution of the template SN spectra. Typically, the phases are relative to the B-maximum for SNe Ia and Ib/c and to the explosion epoch for SNe II.



**Fig. 4.** The phases determined with GELATO compared to the phases from photometry for a sample of type-Ia SNe. In the bottom panel are the residuals.

1991bg and 1991T). Then, we compared the phases of the best fitting template spectra obtained from the spectral comparison with the phases derived from photometry. The results are plotted in Figure 4. The plot shows that the two phases are in a good



**Fig. 5.** The phases derived with GELATO compared to the phases obtained from photometry for a sample of type-II (black dots) and type-Ib/c (gray dots) SNe. In the bottom panel are the residuals.

agreement. The difference of the phases has a RMS of about 3.1 days in the phase range from 15 to 60 days, while in the range -15 to 15 days it is as small as 1.9 days. The increase of the error with age is expected, because the spectra of SNe Ia change less at late times.

Similar tests done with a set of type-II and type-Ib/c SNe give RMS of about 10 days for both samples (see Figure 5). The errors are larger compared to those of type-Ia SNe due to the heterogeneous behaviour of CC SNe (compared to SNe Ia), to the lack of templates with very good temporal coverage and to the uncertainty in the determination of the explosion epoch for SN II.

## 5. Individual spectra

The results of the comparison of our set of 36 spectra with the templates are summarised in Table 4, listing for each object the best template, the phase and the QoF. Figures 6, 7, 8 and 9 show the plots of the spectra of our objects together with their best fitting templates. Spectra are shown in the parent galaxy restframe and are not corrected for extinction. Below we present a short discussion on individual objects.

**SN 2002an** was found on Jan. 22.52 by Nakano et al. (2002) and classified as a type-II supernova by Benetti et al. (2002a). The spectrum consists of a blue continuum with P-Cyg profiles of H Balmer and He I  $\lambda 5876$  lines.  $H_\alpha$  is almost purely in emission (Fig. 6a). The QoF is not high (1.7), which is due to some discrepancies in the fit. In particular  $H_\alpha$  is not well fitted. The most similar template spectrum is that of the type-II SN 1996bw obtained 7 days after its discovery (ASA, Benetti & Turatto 1996). For this template the explosion epoch is not estimated. The spectrum of another type-II SN 1995ad 12 days after its explosion (Pastorello 2003) also provides a satisfactory fit. The expansion velocities deduced from the minima of He I  $\lambda 5876$ ,  $H_\beta$  and  $H_\gamma$  lines are 9300, 9690 and 9800 km s<sup>-1</sup>, respectively.

**SN 2002bh** was found on Feb. 24.3 by Ganeshalingam & Li (2002). Benetti et al. (2002b) classified it as a type-II supernova. A broad  $H_\alpha$  emission line is the only strong feature in the noisy spectrum. Also, broad He I  $\lambda 5876$ , Fe II and  $H_\beta$  features can be identified (Fig. 6b). From the minimum of  $H_\alpha$  an expansion velocity of about 12000 km s<sup>-1</sup> is derived. The best fit is with the type-II SN 1995V spectrum (ASA) 8 days after the explosion (Fassia et al. 1998). The template spectrum does not match well the blue slope of the spectrum, possibly because of some reddening in the host galaxy.

**SN 2002cs** was discovered on May 5.5 by Ganeshalingam et al. (2002). The spectrum is that of a type-Ia supernova, and Riello et al. (2002a) gave an age estimate of  $2 \pm 2$  days before maximum light (Fig. 6c). The expansion velocity deduced from the Si II  $\lambda 6355$  minimum is about 15800 km s<sup>-1</sup>. Both the expansion velocity and the age estimates are in agreement with those by Matheson et al. (2002). The high expansion velocity may be caused by contamination by a high-velocity component (see Mazzali et al. 2005). High-velocity features are particularly strong and blended with the photospheric components in the SNe that belong to the high velocity gradient (HVG) group (see Benetti et al. 2005). In fact, the closest match we found is with the HVG SN 2004dt at a phase of -7 days (Altavilla et al. 2007). The shape of the continuum and interstellar absorption Na I D  $\lambda 5876$  feature (in the Galaxy restframe) of the spectrum suggest the presence of significant extinction. The value of QoF = 1.6 is mainly due to a mismatch in the line velocity suggesting either an even more extreme case of HVG SN than SN 2004dt or an earlier phase. Because of the first phase determination ( $-2 \pm 2$  days instead of -7) SN 2002cs was unfortunately not considered worth of detailed follow-up by the ESC.

**SN 2002dg** was found on May 31.3 by Wood-Vasey et al. (2002) and classified as a type-Ib supernova 2-3 weeks after maximum by Riello et al. (2002b). The spectrum (Fig. 6d) is most similar to that of the type-Ib SN 1998dt at 15 days from R-band maximum (Matheson et al. 2001). For SN 2002dg, adopting a recession velocity of 14000 km s<sup>-1</sup> derived by Riello et al. (2002b) from the parent galaxy emission lines, the expansion velocities measured from the He I  $\lambda 5876$  absorption minima of the SN 2002dg and 1998dt spectra are 9500 and 10900 km s<sup>-1</sup>, respectively. The largest mismatch to the SN 1998dt spectrum is the absorption at 6270 Å (rest frame). If this feature is due to  $H_\alpha$  (see Branch et al. 2002), a transitional type-IIb event may be an alternative classification. Inspection of the fit (see Figure 6) shows that not only the He I features, but also other lines in the spectrum of SN 2002dg are slightly narrower than in SN 1998dt.

**SN 2002dm** was found on May 4.76 by Sanders (2002), Turatto et al. (2002) classified it as a type-Ia SN, giving a phase estimate of about 50 days after maximum light. The high SNR spectrum (Fig. 6e) is almost identical to that of SN 1994ae (ASA) at 92 days after maximum light. The large number of features present in the spectrum and the exceptional resemblance to the 1994ae spectrum lead to the best match among the SNe of the sample (QoF = 9.06).

**SN 2002ej** was discovered on Aug. 9.11 by Puckett & Kerns (2002) and classified as a type-II supernova two weeks after maximum by Desidera et al. (2002). On the noisy spectrum P-Cyg profiles of H Balmer, Fe II and (possibly) Sc II  $\lambda 5240$ , 5527, 5658 lines are present (Fig. 6f). The best fitting template (QoF = 2.94) is the one of the type-IIP SN 1995ad at 24 days after explosion epoch (Pastorello 2003). The expansion velocity of SN 2002ej deduced from the minimum of  $H_\alpha$  line is about 8070 km s<sup>-1</sup>.

**Table 4.** GELATO's best match templates.

| SN     | Type | Best match<br>SN template | QoF | Template phase<br>(days) | Template spectrum<br>reference | Phase reference                       |
|--------|------|---------------------------|-----|--------------------------|--------------------------------|---------------------------------------|
| 2002an | II   | 1996bw                    | 1.7 | 7 *                      | ASA, Benetti & Turatto (1996)  | 1995ad, 12d - Pastorello (2003)       |
| 2002bh | II   | 1995V                     | 1.4 | 8                        | ASA                            | Fassia et al. (1998)                  |
| 2002cs | Ia   | 2004dt                    | 1.6 | -7                       | Altavilla et al. (2007)        |                                       |
| 2002dg | Ib   | 1998dt                    | 1.7 | 15 **                    | ASA                            | Matheson et al. (2001)                |
| 2002dm | Ia   | 1994ae                    | 9.1 | 92                       | ASA                            |                                       |
| 2002ej | II   | 1995ad                    | 2.9 | 24                       | Pastorello (2003)              |                                       |
| 2002hg | II   | 1999em                    | 2.4 | 41                       | Elmhamdi et al. (2003)         |                                       |
| 2002hm | II   | 1998ce                    | 3.8 | 10 *                     | ASA, Patat & Turatto (1998)    | 1995ad, 12d - Pastorello (2003)       |
| 2002hy | Ib   | 2001gh                    | 1.0 | 11 *                     | ASA, Altavilla et al. (2001)   | 1993J, 4d - Barbon et al. (1995)      |
| 2003hg | II   | 1995V                     | 2.1 | 8                        | ASA                            | Fassia et al. (1998)                  |
| 2003hn | II   | 1995ad                    | 2.4 | 10                       | Pastorello (2003)              |                                       |
| 2003ie | II   | 1998A                     | 1.2 | 37                       | Pastorello et al. (2005a)      |                                       |
| 2004G  | II   | 1993S                     | 2.4 | 90 *                     | ASA                            | 1995ad, 100d - Pastorello (2003)      |
| 2004aq | II   | 1991al                    | 2.9 | 25 *                     | ASA                            | 2001du, 18d - Smartt et al. (2003)    |
| 2004bs | Ib   | 1998dt                    | 2.0 | 17 **                    | ASA                            | Matheson et al. (2001)                |
| 2004cc | Ic   | 1994I                     | 1.4 | 10                       | Filippenko et al. (1995)       |                                       |
| 2004dg | II   | 2001du                    | 4.8 | 18                       | Smartt et al. (2003)           |                                       |
| 2004dk | Ic   | 2004aw                    | 1.4 | 4                        | Taubenberger et al. (2006)     |                                       |
| 2004dn | Ic   | 2004aw                    | 1.4 | 4                        | Taubenberger et al. (2006)     |                                       |
| 2004fe | Ic   | 1994I                     | 1.9 | -3                       | Filippenko et al. (1995)       |                                       |
| 2004go | Ia   | 1996X                     | 2.2 | 24                       | Salvo et al. (2001)            |                                       |
| 2005G  | Ia   | 1994D                     | 3.5 | 11                       | Patat et al. (1996)            |                                       |
| 2005H  | II   | 2002gd                    | 1.0 | 6                        | Pastorello (2003)              |                                       |
| 2005I  | II   | 2003gd                    | 3.3 | 101                      | ASA                            | Hendry et al. (2005)                  |
| 2005N  | Ib   | 1990I                     | 2.1 | 88                       | Elmhamdi et al. (2004)         |                                       |
| 2005V  | Ic   | 2004aw                    | 1.3 | 22                       | Taubenberger et al. (2006)     |                                       |
| 2005ab | II   | 1997du                    | 1.5 | 26 *                     | ASA, Patat (1997)              |                                       |
| 2005ai | Ia   | 1994D                     | 2.7 | 24                       | Patat et al. (1996)            |                                       |
| 2005br | Ib   | 1997X                     | 1.9 | 40                       | ASA                            | 1990U, 48d - Piemonte (1996)          |
| 2005bs | Ia   | 1996X                     | 3.3 | 31                       | Salvo et al. (2001)            |                                       |
| 2005cb | Ic   | 1994I                     | 2.5 | 1                        | Filippenko et al. (1995)       |                                       |
| 2005ce | Ib/c | 1996aq                    | 2.0 | 5 *                      | ASA                            | 1994I, 10d - Filippenko et al. (1995) |
| 2005de | Ia   | 2005cf                    | 2.8 | -5                       | Garavini et al. (2007)         |                                       |
| 2005dv | Ia   | 2002bo                    | 2.9 | 0                        | Benetti et al. (2004)          |                                       |
| 2005dz | II   | 2007T                     | 1.4 | 4 *                      | ASA, Benetti et al. (2007)     | 2002gd, 6d - Pastorello (2003)        |
| 2005kl | Ic   | 2004aw                    | 1.2 | 4                        | Taubenberger et al. (2006)     |                                       |

Notes:

Phases are relative to the B-maximum epoch for type-Ia and Ib/c SNe and to explosion epoch for type-II SNe.

\* spectral epoch relative to the discovery date. In these cases no reference of the explosion epoch is found and, when available, the second best fitting template spectrum with phase relative to the explosion epoch is reported in the "Phase reference" column.

\*\* relative to the R-maximum

**SN 2002hg** was found on Oct. 28.22 by Boles & Schwartz (2002) and classified as a type-II supernova few weeks past maximum light by Pignata et al. (2002a). The spectrum shows strong P-Cyg profiles of H Balmer, Fe II, Ca II (H, K plus IR-triplet), Na I D, O I  $\lambda 7774$ , Sc II, Ba II  $\lambda\lambda 4934, 6142$  lines (Fig. 6g) and is well-fitted (QoF = 2.4) by a type-II SN 1999em spectrum taken 41 days after explosion (Elmhamdi et al. 2003). The expansion velocity of SN 2002hg deduced from the  $H_\alpha$  line profile is about 6900 km s<sup>-1</sup>.

**SN 2002hm** was detected on Nov. 5.16 by Boles (2002) and classified as a type-II supernova 30 days after maximum light by Pignata et al. (2002b). The rather blue continuum is overimposed by P-Cyg profiles of H Balmer, Fe II, Ca II lines (Fig. 6h). The best fit to this spectrum is provided by the type-II SN 1998ce spectrum at 10 days after discovery (ASA, Patat & Turatto 1998). The SN 2002hm spectrum is also well fitted by SN 1995ad 12 days after explosion (Pastorello 2003),

in agreement with the fact the Na I D feature, typical of type-II SNe at more advanced epochs, is not present yet, thus suggesting an earlier phase than that proposed by Pignata et al. (2002b). The expansion velocities deduced from the  $H_\alpha$  and  $H_\beta$  absorption minima in the SN 2002hm spectrum are about 9500 and 8100 km s<sup>-1</sup>, respectively.

**SN 2002hy** was found on Nov. 12.1 by Monard (2002) and classified as a peculiar type-Ib supernova by Benetti et al. (2002c). The blue continuum is overimposed with strong He I lines at  $\lambda\lambda 3889, 4471, 5015, 5876, 6678, 7065$  (Fig. 6i). As Benetti et al. (2002c) mentioned, the He I emission peaks are blueshifted on average by 1800 km s<sup>-1</sup>. Despite the peculiarity of the object, GELATO finds a matching spectrum that contains the He I features with similar line velocity, the type-II SN 2001gh 11 days after discovery (ASA, Altavilla et al. 2001; Valenti 2003). The second best fitting template is the type-Ib SN 1993J at 4 days after explosion (Barbon et al. 1995), which, however, fails

to reproduce most of the He I features. SN 2001gh is classified as a type-II SN (Altavilla et al. 2001), but because of the presence of strong He lines both SN 2002hy and SN 2001gh should be considered IIb/Ib events.

**SN 2003hg** was discovered on Aug. 18.4 by Moore & Li (2003) and classified as a type-II supernova shortly after explosion (Elias-Rosa et al. 2003). Broad emission lines of  $H_\alpha$  (possibly with a boxy profile), and He I  $\lambda 5876$  are present together with absorptions of  $H_\beta$ , and  $H_\gamma$  (Fig. 6j). The best fit to this spectrum is with that of the type-II SN 1995V 8 days after explosion (ASA, the same as in SN 2002bh case). Despite the different SED, most probably due to reddening (in fact, Na I D is present with an equivalent width (EW) of about  $1.3\text{\AA}$ ), the QoF is high (2.09).

**SN 2003hn** was found on Aug. 25.7 by Evans et al. (2003) and classified as a type-II supernova approximately two weeks after explosion by Salvo et al. (2003). The spectrum has a blue continuum and P-Cyg profiles of the  $H_\beta$ ,  $H_\gamma$  and He I  $\lambda 5876$  lines.  $H_\alpha$  is present almost purely in emission (Fig. 7a). The best match of this spectrum is the type-II SN 1995ad spectrum 12 days after explosion date (Pastorello 2003). The interstellar Na I D absorption feature present in the SN 2003hn spectrum suggests some reddening ( $\text{EW}(\text{Na I D}) \approx 0.62\text{\AA}$ , corresponding to a lower limit of  $E(B-V)=0.089$ , see Turatto et al. 2003). The expansion velocities for SN 2003hn deduced from the  $H_\beta$  and  $H_\gamma$  lines are of about  $8700$  and  $8200 \text{ km s}^{-1}$ , respectively.

**SN 2003ie** was found on Sept. 19.8 by Arbour & Boles (2003) and classified as a type-II supernova by Benetti et al. (2003). P-Cyg profiles of  $H_\alpha$ ,  $H_\beta$ , Fe II, Sc II, Na I D and Ba II lines are superimposed on red continuum (Fig. 7b). The expansion velocity deduced from the  $H_\alpha$  absorption minimum is about  $5500 \text{ km s}^{-1}$ . The best fit to this spectrum is with that of the peculiar type-II SN 1998A 37 days after explosion (Pastorello et al. 2005a). Like in SN 1998A the  $H_\alpha$  emission shows a significant shift of about  $2100 \text{ km s}^{-1}$  towards the blue. This effect is seen also in SN 1987A and in other type-II SNe (see Pastorello et al. 2005a, for discussion).

**SN 2004G** was found on Jan. 19.8 by Nakano et al. (2004) and classified as a type-II supernova about 5 months after explosion by Elias-Rosa et al. (2004a). The best fit to the SN 2004G spectrum (Fig. 7c) is with the type-II SN 1993S 90 days after its discovery (ASA). The spectrum is well-fitted also by the type-II SN 1995ad spectrum 100 days past explosion (Pastorello 2003). The expansion velocities deduced from the  $H_\alpha$  and  $H_\beta$  absorption minima are about  $6700$  and  $4900 \text{ km s}^{-1}$ , respectively.

**SN 2004aq** was discovered on Mar. 2.1 by Armstrong & Buczynski (2004) and classified as a type-II supernova one month after explosion by Elias-Rosa et al. (2004b). The spectrum shows P-Cyg profiles of  $H_\alpha$ ,  $H_\beta$ , Ca II and Fe II lines superimposed on a rather blue continuum (Fig. 7d). The best fit to this spectrum is a type-II SN 1991al spectrum taken 25 days after discovery (ASA). The minima of the  $H_\alpha$  and  $H_\beta$  absorption components on the SN 2004aq spectrum are blueshifted by about  $7700$  and  $6600 \text{ km s}^{-1}$ , respectively, very similar to those of SN 1991al ( $7700$  and  $6500 \text{ km s}^{-1}$ ). The spectrum of SN 2004aq is also well fitted by that of the type-II SN 2001du 18 days after explosion (Smartt et al. 2003).

**SN 2004bs** was found on May 16.9 by Armstrong (2004) and classified as a type-Ib supernova about 3 weeks past maximum by Pignata et al. (2004a). The spectrum is dominated by He I  $\lambda 5876$ ,  $6678$ ,  $7065$  lines with velocities of about  $10800$ ,  $10200$  and  $10000 \text{ km s}^{-1}$ , respectively (Fig. 7e). Lines of Fe II, O I and Ca II are also present in the spectrum. The best matching

template is the type-Ib SN 1998dt (ASA), 17 days after R-band maximum (Matheson et al. 2001).

**SN 2004cc** was found on Jun 10.3 by Monard & Li (2004) and classified as a type-I supernova by Matheson et al. (2004) and type-Ic supernova one week before maximum by Foley et al. (2004). P-Cyg profiles of Fe II, Na I D (possibly blended with He I  $\lambda 5876$ ), Si II and Ca II are present on the highly reddened spectrum (Fig. 7f). Strong Na I D interstellar absorption is detected in the host galaxy restframe ( $\text{EW} \approx 4.1\text{\AA}$ ). The best fit to this spectrum is provided by the type-Ic SN 1994I 10 days after B maximum (Filippenko et al. 1995), although the Na I D (+ He I) absorption and Fe II features in SN 2004cc are bluer (i.e. with a higher expansion velocity) than those of SN 1994I. The deep O I feature in the SN 1994I spectrum is not present in SN 2004cc, making this object rather peculiar.

**SN 2004dg** was discovered on Jul 19.8 by Vagnozzi et al. (2004) and classified as a type-II supernova by Elias et al. (2004). The spectrum shows P-Cyg profiles of  $H_\alpha$ ,  $H_\beta$ , Ca II H&K, Fe II and Ti II lines (Fig. 7g). There is a narrow emission component, probably due to a nearby H II region, on the broad  $H_\alpha$  emission profile. The recession velocity deduced from this narrow emission line is of about  $1760 \text{ km s}^{-1}$ . Adopting this recession velocity, the photospheric velocities deduced from  $H_\alpha$  and  $H_\beta$  are about  $8420$  and  $6970 \text{ km s}^{-1}$ , respectively. The spectrum of the type-II SN 2001du 18 days from explosion (Smartt et al. 2003) is the best match. Our algorithm provides a very high QoF = 4.76, despite a stronger  $H_\alpha$  emission in SN 2004dg and a slight difference in SED, probably caused by reddening. In fact, on the noisy continuum a clear Na I D interstellar absorption feature with  $\text{EW} \approx 1.9\text{\AA}$  is detected, corresponding to  $E(B-V) = 0.29$  (Turatto et al. 2003).

**SN 2004dk** was found on Aug 1.2 by Graham & Li (2004a) and classified as a type-Ic supernova by Patat et al. (2004a). P-Cyg profiles of Ca II, Fe II, Na I, Si II and O I lines are present in the spectrum (Fig. 7h). The spectrum is similar to that of the type-Ic SN 2004aw 4 days after B maximum light (Taubenberger et al. 2006), though the O I and Ca II absorption profiles of the SN 2004aw spectrum are significantly bluer than those of 2004dk. The absorption minima of Si II  $6355\text{\AA}$  and O I  $7774\text{\AA}$  in the SN 2004dk spectrum suggest expansion velocities of about  $9200$  and  $7300 \text{ km s}^{-1}$ , respectively. A narrow  $H_\alpha$  emission probably due to a nearby H II region is present. The second best fit to this spectrum is by that of SN 1994I 3 days before maximum light (Filippenko et al. 1995), as mentioned in Patat et al. (2004a).

**SN 2004dn** was discovered on Jul. 29.4 by Graham & Li (2004b) and classified as a type-Ic supernova few days before maximum light by Patat et al. (2004b). Spectral features of Si II, O I and Ca II are clearly visible (Fig. 7i). The expansion velocities deduced from Si II  $6355\text{\AA}$  and O I  $7774\text{\AA}$  minima are of about  $10500$  and  $10200 \text{ km s}^{-1}$ , respectively. The best fitting template is again that of the type-Ic SN 2004aw 4 days after maximum (Taubenberger et al. 2006). Having the same best fitting template means that the spectra of SN 2004dn and 2004dk are also similar.

**SN 2004fe** was discovered on Oct. 30.3 by Pugh et al. (2004) and classified as a type-Ic supernova a few days before maximum by Modjaz et al. (2004). The spectrum (Fig. 7j) shows P-Cyg profiles of Ca II, Fe II, Na I D, and O I lines. The best fitting template spectrum is that of the type-Ic SN 1994I 3 days before B maximum (Filippenko et al. 1995). The absorption at about  $6170\text{\AA}$  is probably due to Si II  $\lambda 6355$ , while the one at



about 6360Å is possibly either weak  $H_\alpha$  or C II  $\lambda 6580$  (see Valenti et al. 2008).

**SN 2004go** was found on Nov. 18.3 by Li et al. (2004) and classified as a type-Ia supernova 3-4 weeks past maximum by Navasardyan et al. (2004). The expansion velocity deduced from Si II 6355Å absorption minimum is about 10200 km s<sup>-1</sup>. The spectrum (Fig. 8a) is very similar to that of the type-Ia SN 1996X 24 days after maximum light (Salvo et al. 2001). The spectra of SN 1994D (Patat et al. 1996) and 2002bo (Benetti et al. 2004) 24 and 28 days after their B band maxima also provide good fits.

**SN 2005G** was found on Jan. 14.6 by Graham et al. (2005a) and classified as a type-Ia supernova about 10 days past maximum by Navasardyan et al. (2005). Ganeshalingam et al. (2005) report that a spectrum of SN 2005G taken 2 days before ours shows a narrow Si II 6355Å absorption, a blend of two S II absorptions around 5500Å and a flux density drop blueward of Ca II H&K lines. The Si II and S II features peculiarities are present in our spectrum as well (Fig. 8b), but we cannot confirm the blue flux decline, because of the limited spectral range. Nevertheless, the spectrum closely resembles (QoF = 3.5) that of the type-Ia SN 1994D 11 days after maximum light (Patat et al. 1996). The blueshift of Si II 6355Å minimum is of 9600 km s<sup>-1</sup>.

**SN 2005H** was found on Jan. 15.2 by Graham et al. (2005b) and classified as a young type-II supernova by Pastorello et al. (2005b). The spectrum is dominated by a blue continuum with overimposed P-Cyg profiles of  $H_\beta$ , Fe II and He I (Fig. 8c).  $H_\alpha$  is also present, with broad emission and a shallow absorption. The  $H_\beta$  and He I absorption minima are blueshifted by about 6600 and 6800 km s<sup>-1</sup>, respectively. The best fitting template to this spectrum is that of the SN 2002gd, a low line velocity Nipoor SN IIP 6 days after explosion (Pastorello et al. 2004). The featureless spectrum the peculiar line profiles lead, however, to a very low QoF = 1.01.

**SN 2005I** was discovered on Jan. 15.6 by Graham et al. (2005b). Pastorello et al. (2005b) classified it as a type-II supernova about 3 months after the explosion. The spectrum is characterised by a red continuum and narrow P-Cyg profiles of  $H_\alpha$ ,  $H_\beta$ , Ca II and Fe II lines (Fig. 8d). The expansion velocities deduced from the  $H_\alpha$  minimum is about 4900 km s<sup>-1</sup>. The best match is with the type-II SN 2003gd spectrum (ASA). Adopting for SN 2003gd the explosion epoch found by Hendry et al. (2005), the template is at an epoch of 101 days from the explosion, in good agreement with the phase estimate by Pastorello et al. (2005b).

**SN 2005N** was found on Jan. 19.6 by Puckett et al. (2005a) and classified as a type-Ib/c supernova in the nebular phase by Taubenberger et al. (2005a). The spectrum shows strong emission lines of Mg I  $\lambda 4571$ , Na I D, [O I]  $\lambda 6300$ , 6364, [Ca II]  $\lambda 7291$ , 7323 and Ca II (Fig. 8e). The best fit to this spectrum is with the type-Ib SN 1990I spectrum 88 days after maximum light (Elmhamdi et al. 2004), which, however, shows weaker [O I] emissions.

**SN 2005V** was found on Jan. 30.2 by Mattila et al. (2005) and classified as a type-Ib/c supernova by Taubenberger et al. (2005b). The spectrum shows P-Cyg profiles of Fe II, Na I D, O I and Ca II lines overimposed on a very red continuum (Fig. 8f). A narrow  $H_\alpha$  emission line, due to an underlying H II region, is present. The best match of this spectrum is with the type-Ic SN 2004aw 22 days after the maximum light (Taubenberger et al. 2006). The shape of the continuum and the presence of a deep Na I D absorption line (EW = 5.4Å) in the host galaxy restframe, suggest that SN 2005V is affected by heavy extinction (E(B-V) = 0.9, Turatto et al. 2003). The absorption feature at 6200Å on the

SN 2005V spectrum is most likely due to Si II (possibly blended with  $H_\alpha$ ). There is no evidence of He I lines.

**SN 2005ab** was discovered on Feb. 5.6 by Nakano & Kadota (2005). Benetti & Di Mille (2005) classified it as a type-II SN shortly after its explosion. On the very noisy spectrum (SNR  $\approx 6$ ) a relatively broad ( $\sim 5000$  km s<sup>-1</sup>)  $H_\alpha$  emission line is present (Fig. 8g). The best fitting template spectrum is that of the type-II SN 1997du 26 days after its discovery (ASA, Patat 1997). The minimum of the  $H_\beta$  line absorption component in the SN 1997du spectrum is blueshifted by about 6900 km s<sup>-1</sup>. Despite the low SNR, the absorptions at about 5770Å, 5110Å and 4950Å seem to be fitted by the SN 1997du absorptions of the Na I D 5892Å, Fe II 5169Å and Fe II 5110Å lines, therefore the phase of SN 2005ab could be more advanced than reported by Benetti & Di Mille (2005).

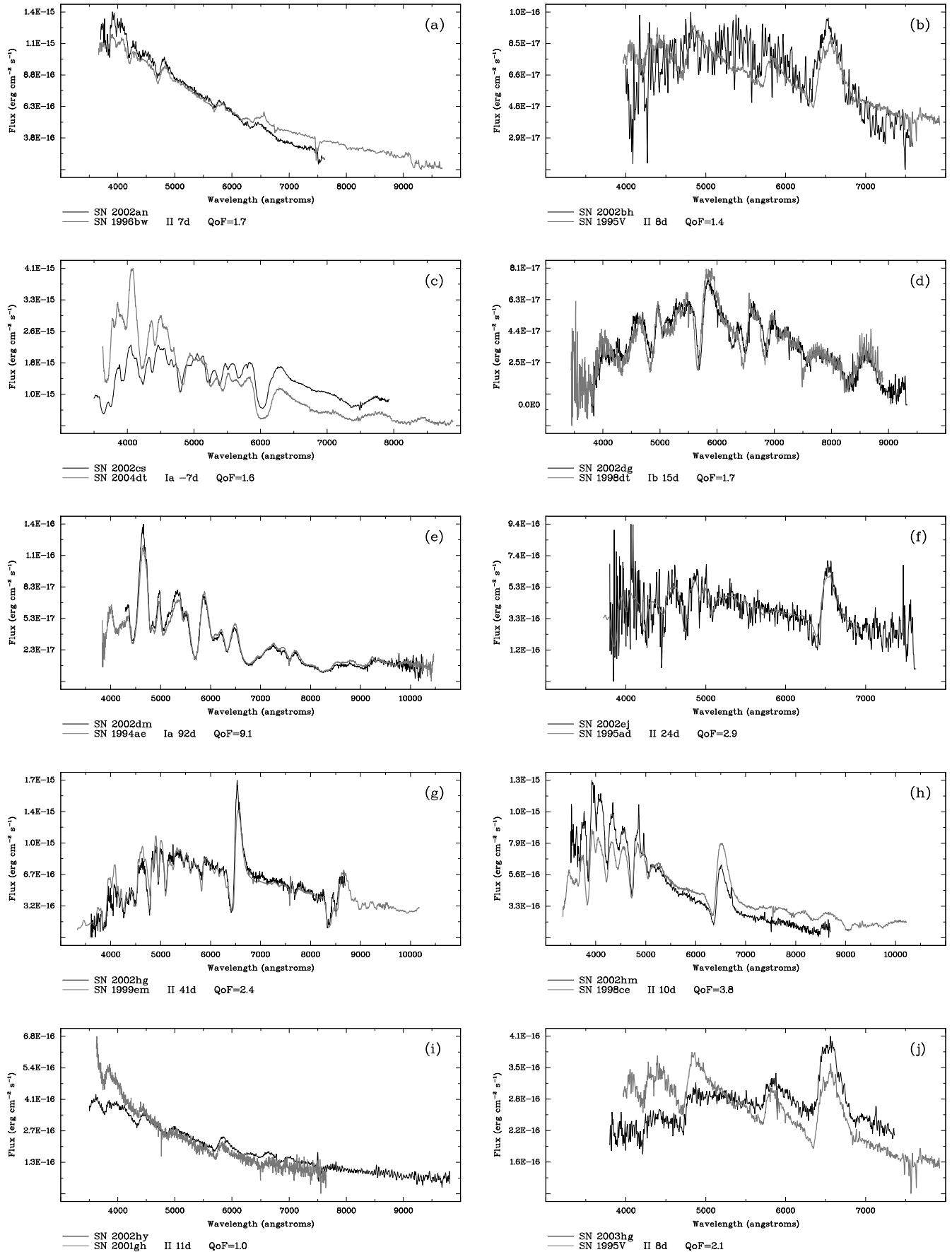
**SN 2005ai** was found on Feb. 12.23 by Puckett et al. (2005b) and classified as a type-Ia supernova about one month past maximum light by Taubenberger et al. (2005c). The spectrum is that of a typical type-Ia SN (Fig. 8h), and SN 1994D 24 days after the maximum light (Patat et al. 1996) yields the best match. This spectrum is similar to the spectrum of SN 2004go of the present sample.

**SN 2005br** was detected on Mar. 28.1 by Monard (2005a) and classified as a type-Ib supernova about 40 days past maximum by Turatto et al. (2005). The reddened spectrum shows features of He I (probably blended with Na I D), O I and Ca II (Fig. 8i). Also, a rather strong (EW  $\approx 2.6$ Å) interstellar Na I D absorption line is detected. The photospheric expansion velocity deduced from He I 5876Å is about 9000 km s<sup>-1</sup>. The best fit to this spectrum is achieved with the type-Ib SN 1997X 40 days after discovery (ASA). However, the O I 7774Å line is shallower (probably contaminated by a telluric feature and less blueshifted) in 1997X. Also, a SN 1990U spectrum (ASA) provides a good fit. Adopting the B maximum epoch given by Piemonte (1996) for SN 1990U, the template spectrum phase is 48 days.

**SN 2005bs** was found on Apr. 19.1 by Monard (2005b), and Turatto et al. (2005) classified it as a type-Ia supernova. The spectrum (Fig. 8j) resembles very well (QoF = 3.33) that of the type-Ia SN 1996X 31 day after the maximum light (Salvo et al. 2001), in agreement with the estimate by Turatto et al. (2005).

**SN 2005cb** was found on May 13.22 by Jacques et al. (2005) and classified as a type-Ib/c supernova at about 10 days after maximum by Turatto et al. (2005). P-Cyg profiles of Fe II, Na I D, Si II, O I and Ca II are present in the spectrum (Fig. 9a). The expansion velocities deduced from the minima of Si II and O I features are about 9500 and 11000 km s<sup>-1</sup>, respectively. The best fitting template is that of the type-Ic SN 1994I 1 day after B maximum light (Filippenko et al. 1995). SN 2005cb seems to be slightly redder than 1994I at maximum, and has a stronger O I with a higher line velocity.

**SN 2005ce** was found on May 28.5 by Pugh & Li (2005) and classified as a type-Ib/c supernova a few days after explosion by Stanishev et al. (2005a). The spectrum has a blue continuum with several P-Cyg profiles of Fe II, Ca II lines and moderately weak absorptions at about 5700Å, 6496Å, 6850Å and 7060Å due to He I, with expansion velocities of about 8980, 8170, 9100 and 9140 km s<sup>-1</sup>, respectively (Fig. 9b). However, the best fit to this spectrum is provided by the type-Ic SN 1996aq 5 days after discovery (ASA). The spectrum is also similar to that of SN 1994I 10 days after B maximum, though in the SN 2005ce spectrum the O I feature is much weaker (if any). The deep absorption at about 6294Å is most likely due to  $H_\alpha$  (probably blended with Si II and C II  $\lambda 6580$ ). This is supported by the identifi-



**Fig. 6.** The comparison of the ESC SN spectra of non-ESC targets with their best fitting templates. The spectra are in the parent galaxy restframe and not corrected for extinction. The black lines are the ESC spectra, while the gray ones display template spectra.

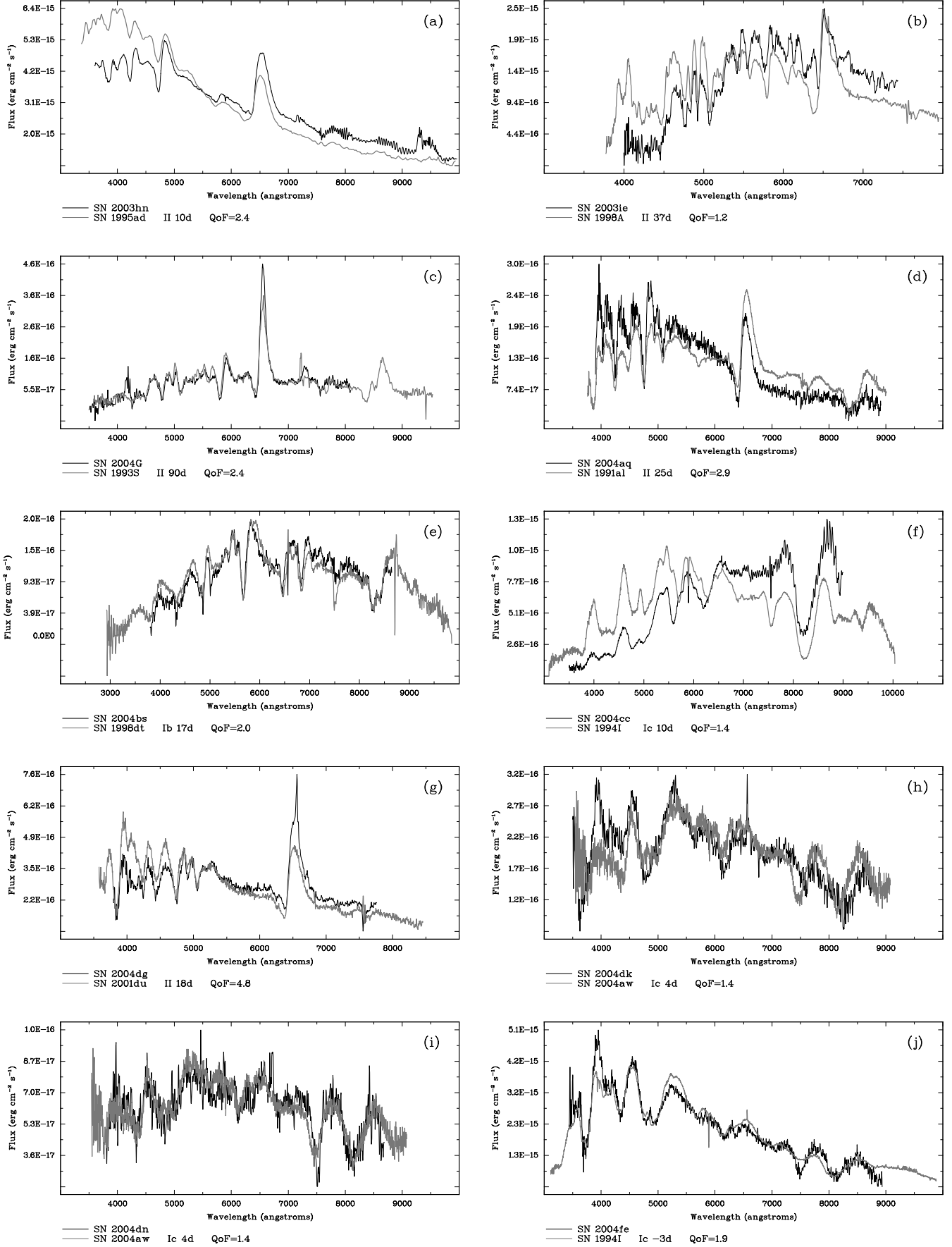


Fig. 7. Same as Fig. 6.

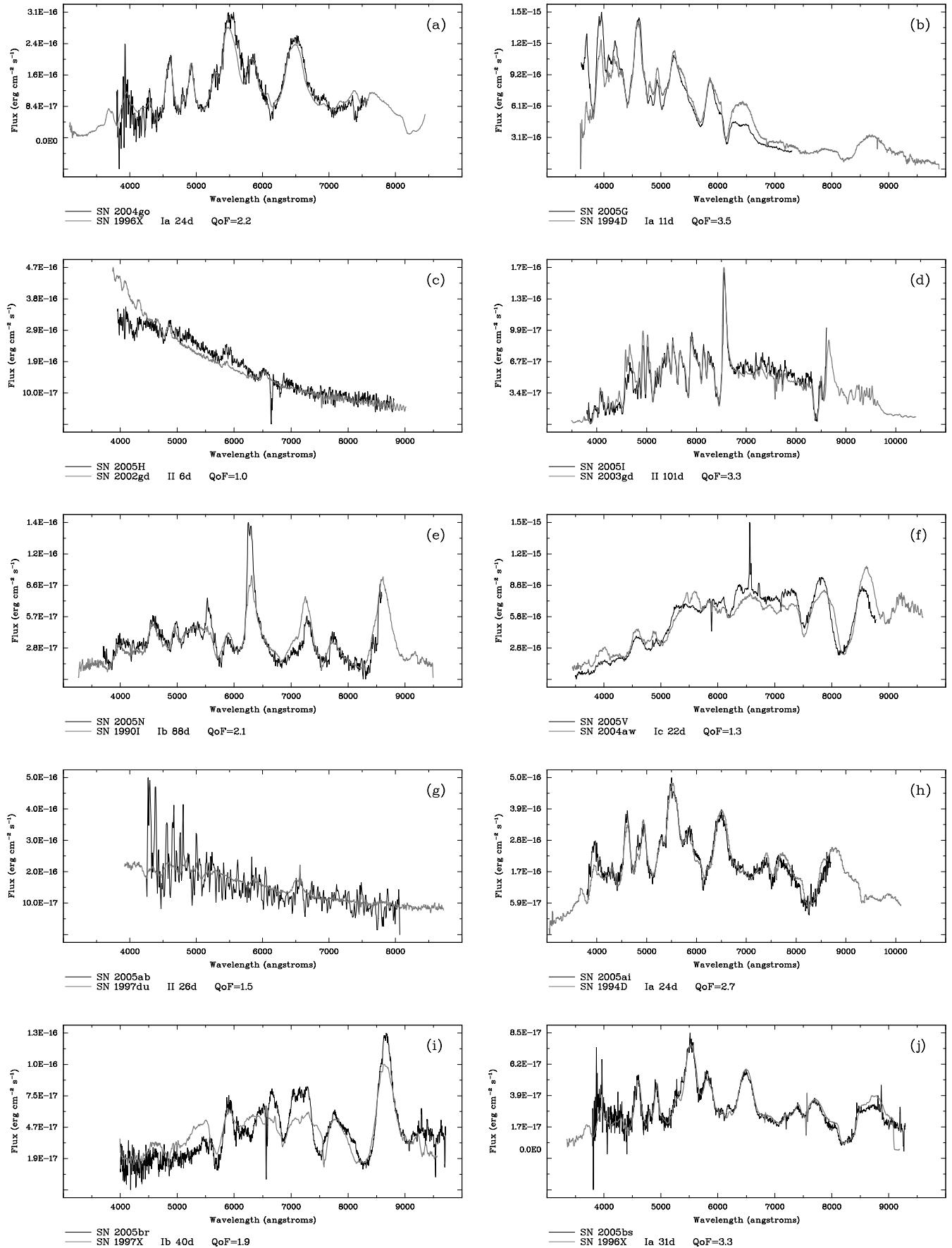
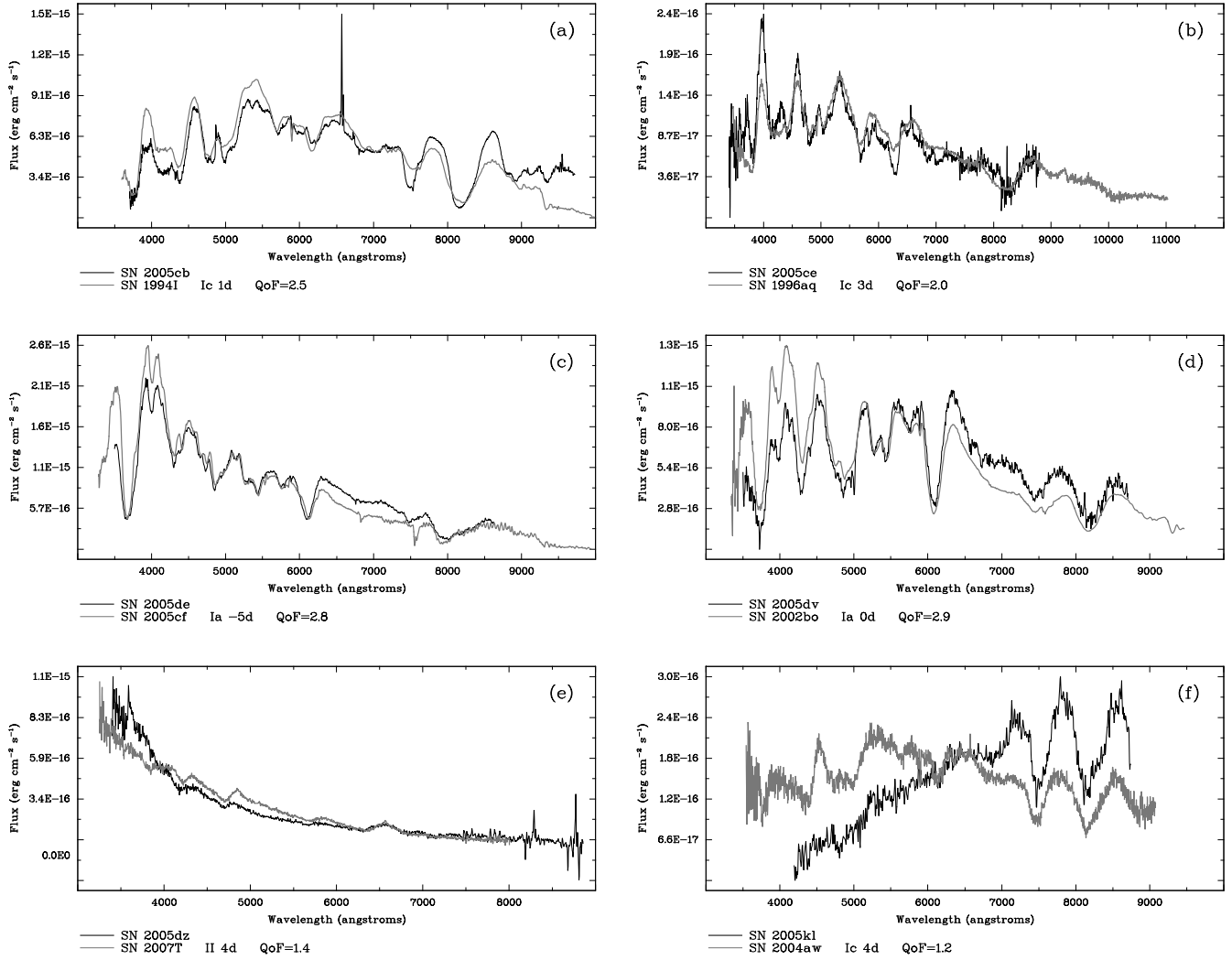


Fig. 8. Same as Fig. 6.



**Fig. 9.** Same as Fig. 6.

cation of an absorption at about  $4689\text{\AA}$  with  $H_\beta$ . The presence of  $H_\alpha$  in various SN Ib/c was suspected (see Branch et al. 2002; Elmhamdi et al. 2006). Usually the  $H_\alpha$  line optical depth is small and no apparent  $H_\beta$  is detected, while in this case the  $H_\alpha$  feature is strong and there is also some hint of  $H_\beta$  presence. With these identifications the photospheric expansion velocities derived from  $H_\alpha$  and  $H_\beta$  lines are of about  $12300$  and  $10600$   $\text{km s}^{-1}$ . Although the best fits found by our program are with type-Ic SNe, SN 2005ce is a rare and a very interesting example of an intermediate case between a Ib (with possibly some contamination of H) and Ic event.

**SN 2005de** was discovered on Aug. 2.28 by Lee et al. (2005) and classified as a type-Ia supernova one week before maximum by Wang & Baade (2005). Our spectrum of SN 2005de shows P-Cyg lines of Ca II, Fe II, S II and Si II (Fig. 9c). The Ca II near-infrared triplet seems to be present with two components. This was noted by Wang & Baade (2005) who measured a velocity of about  $20000$   $\text{km s}^{-1}$  for the bluer component, in agreement with our spectrum where the Ca II absorption minimum is blueshifted by  $20200$   $\text{km s}^{-1}$ , taking  $8579\text{\AA}$  as the wavelength reference for the multiplet. Indeed, this high velocity feature is also present in the best fitting template spectrum of the type-Ia SN 2005cf 5 days before the maximum light

(Garavini et al. 2007). Mazzali et al. (2005) find that the presence of high-velocity features is very common, if not ubiquitous, in the early spectra of SNe Ia.

**SN 2005dv** was found on Sep. 4.8 by Dimai & Dainese (2005) and classified as a type-Ia supernova probably before maximum light by Leonard (2005). The minimum of the Si II  $\lambda 6355$  line is blue-shifted by about  $12600$   $\text{km s}^{-1}$  suggesting that the phase of the spectrum is near-maximum (Fig. 9d). The best fitting template is that of the type-Ia SN 2002bo at maximum light (Benetti et al. 2004). The fit reproduces all spectral features rather well, though in the blue region the continuum of SN 2005dv spectrum is weaker, probably due to some reddening. This is confirmed by the presence of a Na I D absorption line ( $\text{EW} \approx 2.3\text{\AA}$ ) in the rest frame of the host galaxy, as noted also by Leonard (2005).

**SN 2005dz** was found on Sep. 10 by Puckett et al. (2005c) and classified as a young type-II supernova by Stanishev et al. (2005b). The blue continuum of the spectrum is superimposed by broad and shallow P-Cyg profiles of H Balmer and He I  $\lambda 5876$  lines (Fig. 9e).  $H_\alpha$  is present mostly in emission. The expansion velocities derived from the  $H_\alpha$  and  $H_\beta$  absorptions are about  $12200$  and  $10600$   $\text{km s}^{-1}$ , respectively. The best fitting template spectrum is that of the type-II SN 2007T 4 days

after discovery (Benetti et al. 2007), although the expansion velocities of 2007T are smaller. The SN 2005dz spectrum is also similar to that of the type-II SN 2002gd 6 days after explosion (Pastorello et al. 2004).

**SN 2005kl** was discovered on Nov. 22 by Dimai & Migliardi (2005) and classified as a type-Ic supernova by Taubenberger et al. (2005d). P-Cyg profiles of O I, Ca II and also absorptions due to Si II and Fe II are present in the spectrum (Fig. 9f). The red continuum suggests that the SN is heavily extinguished. The best fitting template is the type-Ic SN 2004aw 4 days after B maximum (Taubenberger et al. 2006), which was also the case for SN 2004dk and 2004dn. The expansion velocity deduced from the Si II absorption is of about  $10000 \text{ km s}^{-1}$ .

## 6. Summary

The European Supernova Collaboration (ESC) was conceived to perform very detailed studies of nearby SNe Ia and carried out extensive follow-up programs on 15 objects (plus one SN Ic). Integral part of the ESC was a prompt classification program with ToO observations of selected, newly discovered SNe, with the aim to single out candidates for the following intensive monitoring. In this context several tens of SN candidates were observed which did not meet the ESC requirements as to epoch of discovery and SN type. In this paper we have presented and discussed the spectra of these objects which include 8 type-Ia, 13 type-Ib/c (in 2 cases possibly IIb) and 15 type-II SNe. Each SN spectrum has been analysed by means of a new software tool that compares it with a vast database of SN spectra. For each object we have identified the best fit SN template providing type and a phase estimate. Other information such as the identification of the most prominent spectral features, the expansion velocities of the absorbing layers and possible peculiarities have also been reported.

The comparison with ASA spectra has confirmed the previous classification of all objects. Nevertheless, in some cases the new spectral ages differ from the estimates reported in the original IAU circulars. In the case of SN 2002cs the new determination of the spectral age ( $-7$  days) to be compared to the previous one ( $-2 \pm 2$  days), shows the importance of having a reliable and objective classification tool and a complete archive. Had such a tool been available in 2002, SN 2002cs would have become an ESC target for detailed follow-up observations.

The current version of the comparison software, which is now routinely used by the Padova team for the classification of newly discovered SNe, has been presented. In particular, we have discussed the general algorithm and the accuracy of the classification and phase determination. The classification can be considered “safe” when the QoF parameter is larger than 1.4, while for  $\text{QoF} < 1.4$  the type determination must be done “cum grano salis”. Values of QoF smaller than 1 mean that no spectral template similar to the input spectrum is present in the archive. Typical errors in the epoch determination of  $\pm 1.9$  days have been found for SN Ia in the early, fast evolving phases, while for later epochs the uncertainty rises to 3.1 days. Much larger (about 10 days) is the uncertainty on the epoch determination for CC SNe, because of their heterogeneity and lack of the extensively observed templates.

Although this tool already provides satisfactory results, we plan to implement some refinement for what concerns the quantitative measure of the quality of the fits. The SN research community will have access to the tool through a web-based interface that we plan to develop.

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**Table 5.** The archive SNe and spectra.

| SN     | Type  | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|-------|-----------------|--------------------|-----------------------|
| 1937C  | Ia    | 0.0011          | 5                  | 8 – 39                |
| 1969L  | IIP   | 0.0016          | 7                  | 2 – 61                |
| 1974G  | Ia    | 0.0024          | 1                  | 9                     |
| 1978K  | II    | 0.0015          | 2                  | 7683,7687             |
| 1979B  | Ia    | 0.0032          | 5                  | 9 – 47                |
| 1979C  | III   | 0.0053          | 24                 | 5 – 223               |
| 1980K  | III   | 0.0002          | 19                 | 2 – 95                |
| 1980N  | Ia    | 0.0060          | 1                  | 31                    |
| 1981B  | Ia    | 0.0060          | 22                 | -3 – 356              |
| 1982B  | Ia    | 0.0074          | 2                  | 3,28                  |
| 1983G  | Ia    | 0.0039          | 6                  | -1 – 8                |
| 1983N  | Ib    | 0.0017          | 6                  | -8 – 228              |
| 1983U  | Ia    | 0.0039          | 1                  | 14                    |
| 1983V  | Ic    | 0.0055          | 3                  | -9 – -4               |
| 1984A  | Ia    | -0.0009         | 12                 | -7 – 54               |
| 1984E  | III   | 0.0041          | 1                  | 3959                  |
| 1984L  | Ib    | 0.0051          | 3                  | 10 – 61               |
| 1985L  | III   | 0.0029          | 2                  | 13,203                |
| 1986E  | III   | 0.0037          | 5                  | 23 – 5907             |
| 1986G  | Iapec | 0.0018          | 33                 | -6 – 324              |
| 1987A  | IIpec | 0.0011          | 52                 | -76 – 5014            |
| 1987B  | IIInL | 0.0085          | 2                  | 6,7                   |
| 1987K  | IIb   | 0.0027          | 7                  | 0 – 208               |
| 1988A  | IIP   | 0.0051          | 5                  | 3 – 444               |
| 1988G  | Ia    | n.a.            | 1                  | 29                    |
| 1988H  | IIP   | 0.0066          | 5                  | 21 – 874              |
| 1988L  | Ib    | 0.0062          | 8                  | 11 – 138              |
| 1988Z  | IIIn  | 0.0222          | 21                 | 115 – 3773            |
| 1989B  | Ia    | 0.0024          | 20                 | -6 – 348              |
| 1989C  | IIP   | 0.0063          | 3                  | 3 – 58                |
| 1989M  | Ia    | 0.0051          | 12                 | 20 – 421              |
| 1990B  | Ic    | 0.0075          | 20                 | 5 – 148               |
| 1990E  | IIP   | 0.0041          | 21                 | 13 – 537              |
| 1990H  | II    | 0.0053          | 8                  | 2 – 27                |
| 1990I  | Ib    | 0.0097          | 24                 | 0 – 357               |
| 1990K  | II    | 0.0053          | 21                 | 5 – 475               |
| 1990M  | Ia    | 0.0088          | 8                  | 1 – 55                |
| 1990N  | Ia    | 0.0033          | 6                  | -14 – 246             |
| 1990Q  | II    | 0.0064          | 3                  | 3 – 299               |
| 1990S  | IIIn  | 0.0256          | 1                  | 4                     |
| 1990U  | Ic    | 0.0079          | 25                 | -3 – 367              |
| 1990W  | Ib/c  | 0.0049          | 10                 | 1 – 3995              |
| 1990aa | Ic    | 0.0166          | 20                 | 7 – 141               |
| 1990ah | II    | 0.0175          | 1                  | -84                   |
| 1990aj | Iac   | 0.0053          | 5                  | 42 – 82               |
| 1991A  | Ic    | 0.0107          | 8                  | 5 – 96                |
| 1991D  | Ib    | 0.0418          | 14                 | 5 – 78                |
| 1991E  | II    | 0.0240          | 1                  | 4                     |
| 1991H  | II    | 0.0180          | 1                  | 1                     |
| 1991I  | II    | 0.0360          | 1                  | 2                     |
| 1991K  | Ia    | 0.0170          | 3                  | 70 – 122              |
| 1991L  | Ib/c  | 0.0300          | 1                  | 13                    |
| 1991M  | Ia    | 0.0072          | 9                  | 1 – 147               |
| 1991N  | Ic    | 0.0033          | 5                  | 5 – 282               |
| 1991S  | Ia    | 0.0550          | 2                  | 16,19                 |
| 1991T  | Iapec | 0.0058          | 35                 | -12 – 1785            |



Table 5. continued.

| SN     | Type  | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|-------|-----------------|--------------------|-----------------------|
| 1991ah | IIn   | 0.0370          | 3                  | 62 – 84               |
| 1991al | II    | 0.0100          | 4                  | 20 – 28               |
| 1991ar | Ib    | 0.0152          | 2                  | 14,30                 |
| 1991bb | Ia    | 0.0266          | 1                  | 45                    |
| 1991bc | Ia    | 0.0214          | 2                  | 19,49                 |
| 1991bd | Ia    | 0.0127          | 2                  | 16,46                 |
| 1991bg | Iapec | 0.0030          | 21                 | 1 – 203               |
| 1991bj | Iapec | 0.0182          | 1                  | 2                     |
| 1992A  | Ia    | 0.0062          | 35                 | -6 – 406              |
| 1992B  | Ia    | 0.0550          | 1                  | 13                    |
| 1992C  | II    | 0.0101          | 9                  | 15 – 455              |
| 1992D  | IIn   | 0.0500          | 2                  | 7,33                  |
| 1992E  | Ia    | 0.0600          | 2                  | 9,9                   |
| 1992G  | Ia    | 0.0053          | 4                  | -2 – 35               |
| 1992H  | II    | 0.0060          | 29                 | 10 – 403              |
| 1992K  | Iapec | 0.0104          | 6                  | 45 – 45               |
| 1992O  | Ia    | 0.0370          | 4                  | 25 – 25               |
| 1992al | Ia    | 0.0146          | 1                  | 61                    |
| 1992ao | II    | 0.0122          | 25                 | 4 – 1382              |
| 1992av | Ia    | n.a.            | 1                  | 9                     |
| 1992ay | IIn   | 0.0620          | 1                  | 13                    |
| 1992ba | II    | 0.0041          | 3                  | 3 – 150               |
| 1992bb | Ia    | n.a.            | 2                  | 31,31                 |
| 1992bm | II    | 0.0500          | 1                  | -315                  |
| 1993H  | Ia    | 0.0241          | 5                  | 1 – 416               |
| 1993J  | IIf   | -0.0001         | 39                 | 1 – 1264              |
| 1993K  | II    | 0.0091          | 13                 | 31 – 354              |
| 1993L  | Ia    | 0.0064          | 15                 | 16 – 378              |
| 1993M  | Ia    | 0.0901          | 2                  | 18,18                 |
| 1993N  | IIn   | 0.0098          | 11                 | 32 – 655              |
| 1993S  | II    | 0.0320          | 2                  | 33,90                 |
| 1993T  | Ia    | 0.0881          | 1                  | 33                    |
| 1993W  | II    | 0.0180          | 2                  | 2,6                   |
| 1993ad | II    | 0.0172          | 11                 | 3 – 326               |
| 1993ae | Ia    | 0.0190          | 1                  | 10                    |
| 1993af | Ia    | 0.0033          | 7                  | -304 – 318            |
| 1993aj | Ia    | 0.0751          | 1                  | 14                    |
| 1994D  | Ia    | 0.0015          | 42                 | -11 – 373             |
| 1994I  | Ic    | 0.0015          | 50                 | -6 – 146              |
| 1994L  | II    | 0.0068          | 17                 | 31 – 356              |
| 1994M  | Ia    | 0.0232          | 3                  | 15 – 15               |
| 1994N  | II    | 0.0098          | 8                  | 0 – 265               |
| 1994R  | II    | 0.0070          | 1                  | 10                    |
| 1994S  | Ia    | 0.0152          | 1                  | -4                    |
| 1994U  | Ia    | 0.0044          | 1                  | 0                     |
| 1994Z  | II    | 0.0118          | 13                 | 2 – 365               |
| 1994ae | Ia    | 0.0043          | 13                 | -6 – 531              |
| 1994ai | Ic    | 0.0050          | 8                  | 4 – 70                |
| 1994aj | II    | 0.0320          | 30                 | 43 – 540              |
| 1995D  | Ia    | 0.0066          | 8                  | -6 – 364              |
| 1995F  | Ic    | 0.0051          | 5                  | 10 – 260              |
| 1995G  | IIn   | 0.0163          | 21                 | 2 – 942               |
| 1995H  | II    | 0.0047          | 6                  | -10 – 247             |
| 1995J  | II    | 0.0099          | 1                  | 30                    |
| 1995M  | Ia    | 0.0520          | 1                  | 38                    |
| 1995N  | IIn   | 0.0062          | 63                 | 4 – 3374              |
| 1995P  | Ia    | 0.0560          | 1                  | 22                    |
| 1995R  | Ia    | 0.0237          | 1                  | 7                     |
| 1995T  | Ia    | 0.0560          | 1                  | 8                     |

Table 5. continued.

| SN     | Type    | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|---------|-----------------|--------------------|-----------------------|
| 1995U  | Ia      | 0.0556          | 1                  | 5                     |
| 1995V  | II      | 0.0051          | 16                 | 1 – 402               |
| 1995W  | II      | 0.0113          | 21                 | 12 – 780              |
| 1995X  | II      | 0.0052          | 1                  | 28                    |
| 1995Z  | II      | 0.0158          | 2                  | 88,91                 |
| 1995aa | IIIn    | 0.1900          | 1                  | 23                    |
| 1995ac | Iapec   | 0.0500          | 8                  | 0 – 43                |
| 1995ad | II      | 0.0061          | 23                 | 7 – 508               |
| 1995ae | Ia      | 0.0689          | 1                  | 10                    |
| 1995ag | II      | 0.0049          | 2                  | 33,207                |
| 1995ak | Ia      | 0.0227          | 3                  | -1 – 19               |
| 1995al | Ia      | 0.0051          | 10                 | -3 – 166              |
| 1995bb | Ic      | 0.0058          | 1                  | 18                    |
| 1995bd | Iapec   | 0.0154          | 3                  | 16 – 19               |
| 1996A  | II      | 0.0330          | 7                  | 10 – 39               |
| 1996D  | Ic      | 0.0158          | 5                  | 9 – 214               |
| 1996L  | IIIL    | 0.0330          | 16                 | 9 – 336               |
| 1996M  | II      | 0.0200          | 4                  | 3 – 61                |
| 1996W  | II      | 0.0055          | 13                 | 8 – 309               |
| 1996X  | Ia      | 0.0068          | 17                 | -4 – 298              |
| 1996Z  | Ia      | 0.0076          | 3                  | 5 – 269               |
| 1996ae | IIIn    | 0.0052          | 5                  | 7 – 23                |
| 1996al | II      | 0.0061          | 48                 | 1 – 2155              |
| 1996an | II      | 0.0047          | 18                 | 3 – 487               |
| 1996aq | Ic      | 0.0053          | 17                 | 2 – 270               |
| 1996ar | Ia      | 0.0600          | 1                  | 3                     |
| 1996as | II      | 0.0360          | 2                  | 3,3                   |
| 1996bl | Ia      | 0.0360          | 1                  | -3                    |
| 1996bo | Ia      | 0.0175          | 2                  | -6,49                 |
| 1996bw | II      | 0.0181          | 3                  | 7 – 22                |
| 1996bx | Ic      | 0.0600          | 1                  | 19                    |
| 1996cb | IIb     | 0.0024          | 19                 | 12 – 155              |
| 1996cc | II      | 0.0072          | 6                  | 83 – 140              |
| 1997B  | Ic      | 0.0104          | 18                 | 1 – 385               |
| 1997C  | Ia      | 0.0227          | 1                  | 27                    |
| 1997D  | IIpec   | 0.0052          | 16                 | -1 – 383              |
| 1997X  | Ic      | 0.0037          | 22                 | 5 – 101               |
| 1997Y  | Ia      | 0.0160          | 4                  | 31 – 32               |
| 1997Z  | II      | 0.0086          | 5                  | 2 – 7                 |
| 1997ab | IIIn    | 0.0125          | 6                  | 357 – 777             |
| 1997bp | Iapec   | 0.0083          | 12                 | -1 – 414              |
| 1997bq | Ia      | 0.0094          | 1                  | 18                    |
| 1997br | Iapec   | 0.0069          | 13                 | -4 – 404              |
| 1997bs | IIIn    | 0.0024          | 1                  | 14                    |
| 1997bt | II      | 0.0648          | 1                  | 16                    |
| 1997by | Ia      | 0.0453          | 1                  | 3                     |
| 1997cn | Iapec   | 0.0167          | 3                  | 3 – 78                |
| 1997cr | II      | 0.0771          | 2                  | 8,8                   |
| 1997cw | Iapec   | 0.0176          | 9                  | 44 – 106              |
| 1997cy | IIIn    | 0.0642          | 15                 | 8 – 635               |
| 1997dc | Ib      | 0.0115          | 2                  | 6,32                  |
| 1997dd | IIb     | 0.0152          | 1                  | 17                    |
| 1997de | Ia      | 0.0129          | 1                  | 25                    |
| 1997dh | Ic      | 0.0500          | 1                  | 4                     |
| 1997dq | Ib/cpec | 0.0032          | 5                  | 6 – 428               |
| 1997ds | II      | 0.0094          | 1                  | 8                     |
| 1997du | II      | 0.0200          | 2                  | 26,35                 |
| 1997ef | Ib/cpec | 0.0118          | 8                  | 4 – 102               |
| 1997eg | IIIn    | 0.0089          | 4                  | 76 – 547              |

Table 5. continued.

| SN     | Type  | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|-------|-----------------|--------------------|-----------------------|
| 1997ei | Ic    | 0.0107          | 1                  | 25                    |
| 1997ej | Ia    | 0.0223          | 2                  | 32,37                 |
| 1998A  | IIpec | 0.0070          | 10                 | 18 – 397              |
| 1998E  | IIIn  | 0.0080          | 1                  | 374                   |
| 1998R  | II    | 0.0067          | 1                  | 36                    |
| 1998S  | IIIn  | 0.0028          | 5                  | 7 – 489               |
| 1998T  | Ib    | 0.0101          | 3                  | 3 – 27                |
| 1998V  | Ia    | 0.0174          | 1                  | 12                    |
| 1998W  | II    | 0.0119          | 2                  | 6,14                  |
| 1998bn | Ia    | 0.0061          | 1                  | 360                   |
| 1998bp | Ia    | 0.0106          | 2                  | 27,346                |
| 1998bu | Ia    | 0.0031          | 12                 | -7 – 681              |
| 1998bw | Ic    | 0.0085          | 34                 | -9 – 376              |
| 1998ce | II    | 0.0084          | 1                  | 10                    |
| 1998cg | Ia    | 0.1190          | 1                  | 29                    |
| 1998co | Ia    | 0.0182          | 1                  | 31                    |
| 1998cv | Ic    | 0.0270          | 1                  | 28                    |
| 1998cx | Ia    | 0.0197          | 1                  | 18                    |
| 1998dg | Ia    | 0.0082          | 1                  | 203                   |
| 1998dh | Ia    | 0.0089          | 4                  | 8 – 58                |
| 1998dj | Ia    | 0.0137          | 2                  | 4,52                  |
| 1998dk | Ia    | 0.0132          | 2                  | 29,31                 |
| 1998dl | II    | 0.0047          | 2                  | 59,116                |
| 1998dm | Ia    | 0.0065          | 2                  | 23,27                 |
| 1998dn | II    | 0.0013          | 2                  | 43,95                 |
| 1998dq | Ia    | 0.0108          | 1                  | 39                    |
| 1998dt | Ib    | 0.0150          | 7                  | 19 – 125              |
| 1998ee | IIpec | 0.0497          | 1                  | 116                   |
| 1998es | Iapec | 0.0105          | 3                  | -2 – 58               |
| 1998et | IIIn  | 0.0404          | 1                  | 296                   |
| 1998ew | II    | 0.0103          | 1                  | 179                   |
| 1998fa | IIb   | 0.0244          | 5                  | 25 – 77               |
| 1999E  | IIIn  | 0.0260          | 17                 | 8 – 449               |
| 1999J  | Iapec | 0.0334          | 1                  | 21                    |
| 1999P  | Ib/c  | 0.0600          | 2                  | 6,7                   |
| 1999Z  | IIIn  | 0.0504          | 2                  | 31,115                |
| 1999aa | Iapec | 0.0149          | 3                  | 13 – 50               |
| 1999ac | Iapec | 0.0095          | 7                  | -6 – 391              |
| 1999as | Icpec | 0.1270          | 1                  | 54                    |
| 1999br | IIpec | 0.0034          | 8                  | 11 – 99               |
| 1999bv | Ia    | 0.0184          | 1                  | 5                     |
| 1999by | Iapec | 0.0021          | 1                  | 183                   |
| 1999cf | Ia    | 0.0244          | 1                  | 13                    |
| 1999cl | Ia    | 0.0071          | 3                  | 16 – 297              |
| 1999cn | Ic    | 0.0226          | 3                  | 1 – 299               |
| 1999cw | Ia    | 0.0124          | 10                 | 3 – 397               |
| 1999cz | Ic    | 0.0072          | 1                  | 15                    |
| 1999da | Ia    | 0.0123          | 1                  | 60                    |
| 1999dh | II    | 0.0108          | 1                  | 22                    |
| 1999di | Ib    | 0.0164          | 3                  | 9 – 40                |
| 1999dk | Ia    | 0.0152          | 6                  | -14 – 67              |
| 1999dn | Ib    | 0.0094          | 12                 | 6 – 379               |
| 1999dq | Iapec | 0.0145          | 1                  | -6                    |
| 1999eb | IIIn  | 0.0181          | 7                  | 5 – 88                |
| 1999ec | Iac   | 0.0092          | 1                  | 6                     |
| 1999ee | Ia    | 0.0114          | 14                 | -9 – 41               |
| 1999el | IIIn  | 0.0044          | 4                  | 18 – 103              |
| 1999em | IIP   | 0.0024          | 23                 | -2 – 635              |
| 1999et | II    | 0.0163          | 2                  | 0,0                   |

Table 5. continued.

| SN     | Type  | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|-------|-----------------|--------------------|-----------------------|
| 1999eu | IIpec | 0.0042          | 4                  | 5 – 43                |
| 1999ex | Ib/c  | 0.0114          | 8                  | -1 – 13               |
| 1999ey | IIIn  | 0.0931          | 2                  | 4,25                  |
| 1999ga | II    | 0.0047          | 4                  | 40 – 441              |
| 1999ge | II    | 0.0188          | 1                  | 10                    |
| 1999gi | IIP   | 0.0020          | 2                  | 49,173                |
| 1999go | II    | 0.0148          | 2                  | 5,6                   |
| 1999gt | Ia    | 0.2740          | 3                  | 13 – 13               |
| 1999gu | II    | 0.1470          | 2                  | 13,13                 |
| 2000B  | Ia    | 0.0191          | 2                  | 10,19                 |
| 2000C  | Ic    | 0.0127          | 5                  | 17 – 34               |
| 2000D  | II    | 0.0172          | 2                  | 8,19                  |
| 2000E  | Ia    | 0.0044          | 7                  | 14 – 144              |
| 2000H  | IIb   | 0.0130          | 6                  | 9 – 66                |
| 2000M  | II    | 0.0103          | 1                  | 5                     |
| 2000N  | II    | 0.0133          | 2                  | 5,9                   |
| 2000O  | Ia    | 0.0235          | 2                  | 4,9                   |
| 2000P  | IIIn  | 0.0074          | 6                  | 3 – 506               |
| 2000bg | IIIn  | 0.0245          | 1                  | 4                     |
| 2000ck | IIpec | 0.0268          | 1                  | 5                     |
| 2000cm | Ia    | 0.0072          | 1                  | 4                     |
| 2000cn | Ia    | 0.0235          | 2                  | 8,86                  |
| 2000cu | Ia    | n.a.            | 1                  | 2                     |
| 2000cx | Iapec | 0.0081          | 5                  | 1 – 114               |
| 2000da | II    | 0.0244          | 1                  | 19                    |
| 2000db | II    | 0.0023          | 1                  | 16                    |
| 2000de | Ib    | 0.0080          | 4                  | 13 – 14               |
| 2000dg | Ia    | 0.0385          | 1                  | 6                     |
| 2000dj | II    | 0.0158          | 2                  | 7,8                   |
| 2000eo | IIIn  | 0.0108          | 1                  | 10                    |
| 2000ev | IIIn  | 0.0146          | 1                  | 1                     |
| 2000ew | Ic    | 0.0032          | 2                  | 65,109                |
| 2000fc | Ia    | 0.4200          | 1                  | 9                     |
| 2000fe | II    | 0.0141          | 1                  | 11                    |
| 2000fp | II    | 0.3000          | 1                  | 5                     |
| 2001N  | Ia    | 0.0210          | 5                  | 11 – 57               |
| 2001V  | Ia    | 0.0151          | 3                  | 13 – 54               |
| 2001X  | IIP   | 0.0049          | 2                  | 129,468               |
| 2001bb | Ic    | 0.0158          | 4                  | 18 – 74               |
| 2001bc | II    | 0.1950          | 1                  | 8                     |
| 2001bd | II    | 0.0961          | 1                  | 10                    |
| 2001be | Ia    | 0.2410          | 2                  | 9,9                   |
| 2001bg | Ia    | 0.0071          | 2                  | 3,11                  |
| 2001cz | Ia    | 0.0157          | 4                  | 1 – 29                |
| 2001dc | IIP   | 0.0071          | 3                  | 41 – 86               |
| 2001dk | IIP   | 0.0180          | 1                  | 164                   |
| 2001dr | II    | 0.0239          | 1                  | 11                    |
| 2001du | II    | 0.0055          | 1                  | 16                    |
| 2001ed | Ia    | 0.0165          | 1                  | 7                     |
| 2001eh | Ia    | 0.0371          | 17                 | 3 – 69                |
| 2001ep | Ia    | 0.0130          | 25                 | 7 – 103               |
| 2001fh | Iapec | 0.0130          | 2                  | 3,14                  |
| 2001fv | II    | 0.0049          | 2                  | 66,68                 |
| 2001fw | Ib    | 0.0295          | 1                  | 7                     |
| 2001ge | Ia    | 0.2200          | 1                  | 1                     |
| 2001gf | Ia    | 0.1300          | 2                  | 1,1                   |
| 2001gg | II    | 0.6100          | 1                  | 1                     |
| 2001gh | II    | 0.1600          | 2                  | 1,29                  |
| 2001gi | Ia    | 0.2000          | 1                  | 1                     |

Table 5. continued.

| SN     | Type   | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|--------|-----------------|--------------------|-----------------------|
| 2001gj | II     | 0.2700          | 1                  | 1                     |
| 2001ie | Ia     | 0.0308          | 1                  | 4                     |
| 2001ig | IIb    | 0.0030          | 1                  | 188                   |
| 2001io | Ia     | 0.1900          | 3                  | 12 – 12               |
| 2001ip | Ia     | 0.5400          | 3                  | 12 – 1433             |
| 2001is | Ib     | 0.0133          | 2                  | 17,18                 |
| 2001it | II     | 0.0345          | 1                  | 18                    |
| 2002A  | IIIn   | 0.0096          | 1                  | 10                    |
| 2002an | II     | 0.0129          | 1                  | 14                    |
| 2002ap | Icpec  | 0.0021          | 38                 | -7 – 250              |
| 2002bh | II     | 0.0173          | 1                  | 9                     |
| 2002bo | Ia     | 0.0043          | 28                 | -14 – 367             |
| 2002cl | Ic     | 0.0720          | 2                  | 14,14                 |
| 2002cm | II     | 0.0871          | 2                  | 14,14                 |
| 2002cn | Ia     | 0.3020          | 2                  | 14,14                 |
| 2002co | II     | 0.3180          | 1                  | 14                    |
| 2002cr | Ia     | 0.0094          | 5                  | 4 – 46                |
| 2002cs | Ia     | 0.0157          | 1                  | 2                     |
| 2002cv | Ia     | 0.0043          | 10                 | -5 – 26               |
| 2002dg | Ib     | 0.0467          | 1                  | 15                    |
| 2002dj | Ia     | 0.0093          | 9                  | 2 – 287               |
| 2002dm | Ia     | 0.0252          | 1                  | 43                    |
| 2002du | II     | 0.2100          | 1                  | 68                    |
| 2002ej | II     | 0.0162          | 1                  | 21                    |
| 2002eo | II     | 0.0204          | 1                  | 11                    |
| 2002er | Ia     | 0.0091          | 27                 | -11 – 582             |
| 2002gd | II     | 0.0090          | 13                 | 3 – 111               |
| 2002hy | Ibpec  | 0.0127          | 1                  | 3                     |
| 2002ic | Iapec  | 0.0660          | 8                  | 16 – 258              |
| 2002ji | Ib/c   | 0.0049          | 1                  | 5                     |
| 2003G  | IIIn   | 0.0115          | 3                  | 15 – 16               |
| 2003J  | II     | 0.0026          | 1                  | 13                    |
| 2003L  | Ic     | 0.0213          | 1                  | 13                    |
| 2003M  | Iapec? | 0.0242          | 5                  | 12 – 42               |
| 2003Z  | II     | 0.0042          | 12                 | 23 – 149              |
| 2003bg | Icpec  | 0.0044          | 1                  | 4                     |
| 2003cg | Ia     | 0.0041          | 40                 | -8 – 386              |
| 2003dt | Ia     | 0.0142          | 1                  | 2                     |
| 2003du | Ia     | 0.0064          | 10                 | -11 – 72              |
| 2003ei | IIIn   | 0.0268          | 2                  | 61,62                 |
| 2003gd | II     | 0.0021          | 7                  | 15 – 73               |
| 2003gs | Iapec  | 0.0047          | 2                  | 14,26                 |
| 2003hg | II     | 0.0143          | 1                  | 4                     |
| 2003hn | II     | 0.0039          | 1                  | 3                     |
| 2003ie | II     | 0.0023          | 1                  | 3                     |
| 2003jd | Icpec  | 0.0188          | 13                 | 0 – 29                |
| 2004G  | II     | 0.0053          | 1                  | 2                     |
| 2004aq | II     | 0.0140          | 1                  | 8                     |
| 2004aw | Ic     | 0.0158          | 32                 | 1 – 261               |
| 2004dg | II     | 0.0045          | 1                  | 2                     |
| 2004dh | II     | 0.0194          | 2                  | 93,93                 |
| 2004dj | IIP    | 0.0004          | 5                  | 133 – 157             |
| 2004dt | Ia     | 0.0195          | 33                 | -10 – 354             |
| 2004eo | Ia     | 0.0157          | 21                 | 2 – 241               |
| 2004et | II     | 0.0002          | 5                  | 58 – 263              |
| 2004ex | IIb    | 0.0174          | 3                  | 36 – 85               |
| 2004gd | IIIn   | 0.0174          | 1                  | 39                    |
| 2004go | Ia     | 0.0291          | 1                  | 19                    |
| 2004gt | Ib/c   | 0.0055          | 2                  | 24,163                |

**Table 5.** continued.

| SN     | Type    | Redshift<br>(z) | Number<br>of files | Phase range<br>(days) |
|--------|---------|-----------------|--------------------|-----------------------|
| 2005G  | Ia      | 0.0231          | 1                  | 4                     |
| 2005N  | Ib/c    | 0.0163          | 1                  | 3                     |
| 2005W  | Ia      | 0.0087          | 2                  | 1,15                  |
| 2005ab | II      | 0.0154          | 1                  | 4                     |
| 2005au | II      | 0.0182          | 1                  | 15                    |
| 2005aw | Ic      | 0.0133          | 1                  | 62                    |
| 2005ay | IIP     | 0.0027          | 12                 | 1 – 308               |
| 2005bl | Ia      | 0.0241          | 1                  | 33                    |
| 2005br | Ib      | 0.0103          | 1                  | 58                    |
| 2005bs | Ia      | 0.0552          | 1                  | 36                    |
| 2005cb | Ic      | 0.0105          | 1                  | 12                    |
| 2005cf | Ia      | 0.0065          | 31                 | -12 – 77              |
| 2005cq | Ia      | 0.3100          | 1                  | 10                    |
| 2005cs | IIP     | 0.0015          | 17                 | -1 – 222              |
| 2005ip | II      | 0.0071          | 6                  | 3 – 95                |
| 2006G  | II/IIb  | 0.0168          | 1                  | 25                    |
| 2006W  | II/L    | 0.0159          | 1                  | 2                     |
| 2006X  | Ia      | 0.0053          | 2                  | 1,9                   |
| 2006aj | Ib/c    | 0.0330          | 16                 | -7 – 10               |
| 2006ao | II      | 0.0299          | 1                  | 10                    |
| 2006ca | II      | 0.0089          | 1                  | 2                     |
| 2006gi | Ib      | 0.0094          | 1                  | 146                   |
| 2006gy | IIIn    | 0.0188          | 3                  | -31 – 106             |
| 2006gz | Ia      | 0.0236          | 17                 | -13 – 12              |
| 2006jc | Ib/cpec | 0.0056          | 28                 | 3 – 78                |
| 2006ov | IIP     | 0.0053          | 2                  | 39,79                 |
| 2007C  | Ib      | 0.0056          | 1                  | 12                    |
| 2007F  | Ia      | 0.0238          | 1                  | 2                     |
| 2007I  | Ic      | 0.0216          | 1                  | 28                    |
| 2007R  | Ia      | 0.0308          | 1                  | 5                     |
| 2007T  | II      | 0.0135          | 1                  | 4                     |
| 2007af | Ia      | 0.0053          | 1                  | 67                    |
| 2007bj | Ia      | 0.0166          | 1                  | 2                     |
| 2007bm | Ia      | 0.0062          | 5                  | 2 – 28                |
| 2007bt | IIIn    | 0.0400          | 1                  | 21                    |
| 2007bw | IIIn    | 0.1400          | 1                  | 32                    |
| 2007fo | Ib      | 0.0094          | 1                  | 7                     |